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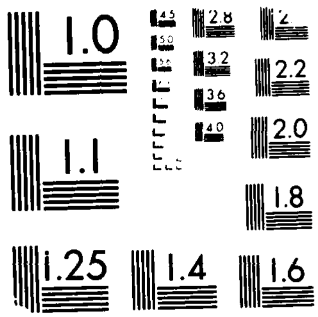

MICROCOPY RESOLUTION TEST CHART

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IENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETEING FORM

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ADVANCED Ada WORKSHOP

Applied Ada Software Engineering

Capt Roger D. Beauman

Capt Michael S. Simpson

Ada Software Engineering Education and Training (ASEET) Team

A-1

APPLIED Ada SOFTWARE ENGINEERING

* Basic Problem
  -- Projection to the 1990's
  -- A Macro Solution
* A Practical Solution
  -- Software Engineering
  -- Ada
* Software Engineering
  -- Goals
  -- Principles
* Why Ada ?
  -- Features of Ada
  -- Software Engineering Applications

BASIC PROBLEM

Projection to the 1990's

* Multiprocessors - Networks and Parallel Architectures
* Distributed Databases
* Hardware Capabilities
* Software Demands
* Hardware Costs

CHANGING COMPUTER TECHNOLOGY

REALTIME AND
PARALLEL PROCESSING

DISTRIBUTED DATABASES

* Central Control Over Data
* Minimize Effort in Storing Data
* "The Ada Package Store"

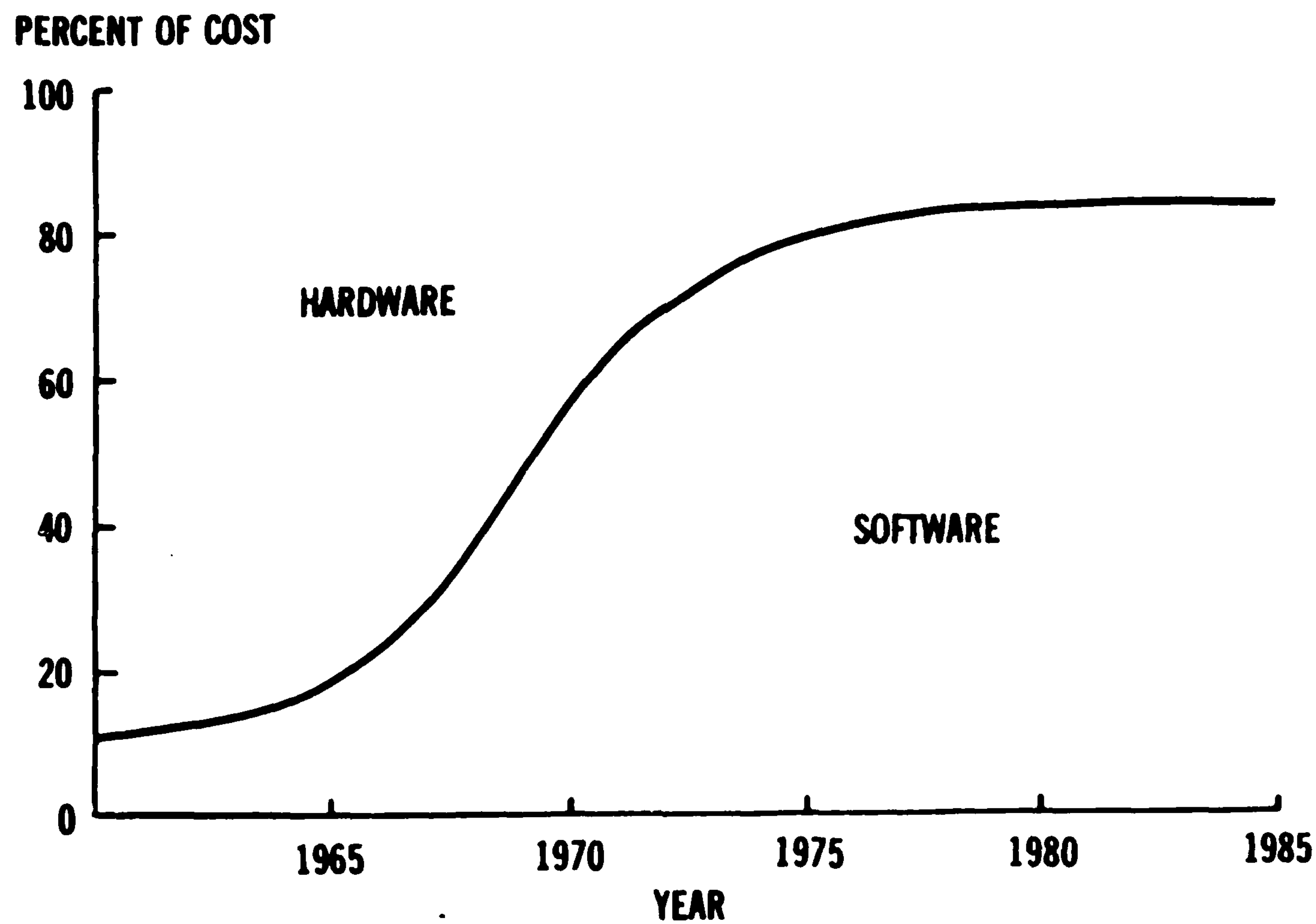
HARDWARE CAPABILITIES

* Mainframe in a Micro
  - -- Intel 80286, 80386, 80486, ???
  - -- Motorola 68000, 68010, 68020, 68030, ???
* Screen Resolution
  - -- Desktop Publishing, CAD/CAM
* Storage Devices
  - -- 100+ MB Hard Disks
  - -- Access Times - 18 ms to 40 ms
* Opens New Fields of Applications

SOFTWARE DEMANDS

* New Users with Consumer Relationships
* Non-Technical Arenas
  -- Need Guarantees
  -- Demand Reliability
* Development is the Key
  -- Design is Paramount
    --- Simplistic Operations; i.e. TV
  -- Costs of Errors
  -- Other Considerations

HARDWARE/SOFTWARE COST TRENDS



A MACRO SOLUTION

* Greater Use of Automation
* Higher Levels of Abstraction
* Reuseability
  -- Isolate Commonality
  -- Create Workable Abstractions
  -- Reuseable Parts Library
* Rapid Prototyping
  -- Gain Insight
  -- Evaluate Design Expectations
  -- Compare Design Alternatives

A solution offered by Edward Lieblein

A PRACTICAL SOLUTION

Software Engineering Myths

* Anyone Can Be a Software Engineer
* Automated Tools = Software Engineering
* Structured Programming = Software Engineering
* Structured Analysis = Software Engineering
* Code Re-use = Software Engineering
* It Will Make Programming Obsolete
* AI Will Make It Effortless
* Fantastic Productivity Gains
* Ada = Software Engineering

SOFTWARE ENGINEERING

A PRACTICAL SOLUTION

* What Is It ?
* Why Is It Needed ?
* The State of the Art
* The State of the Practice
* Why Now ?

CHARACTERISTICS OF DoD SOFTWARE

* Expensive
* Incorrect
* Unreliable
* Difficult to predict
* Unmaintainable
* Not reusable

FACTORS AFFECTING DoD SOFTWARE

* Ignorance of life cycle implications
* Lack of standards
* Lack of methodologies
* Inadequate support tools
* Management
* Software professionals

CHARACTERISTICS OF DoD SOFTWARE REQUIREMENTS

* Large
* Complex
* Long lived
* High reliability
* Time constraints
* Size constraints

THE FUNDAMENTAL PROBLEM

* Our inability to manage the COMPLEXITY of our software systems

* Lack of a disciplined, engineering approach

SOFTWARE ENGINEERING

THE ESTABLISHMENT AND APPLICATION OF SOUND ENGINEERING =>

* Environments
* Tools
* Methodologies
* Models
* Principles
* Concepts

SOFTWARE ENGINEERING

COMBINED WITH =>

* Standards
* Guidelines
* Practices

SOFTWARE ENGINEERING

TO SUPPORT COMPUTING WHICH IS =>

* Understandable
* Efficient
* Reliable and safe
* Modifiable
* Correct

THROUGHOUT THE LIFE CYCLE OF A SYSTEM

SOFTWARE ENGINEERING

* Purposes
* Concepts
* Mechanisms
* Notation
* Usage

PURPOSES

* Create software systems according to good engineering practice

* Manage elements within the software life cycle

CONCEPTS

* Derive the architecture of software systems

* Specify modules of the system

MECHANISMS

* Tools for:
  - Writing operating systems
  - Tuning software
  - Prototyping

* Techniques for:
  - Managing projects
  - Systems analysis
  - Systems design

* Standards for:
  - Coding
  - Metrics
  - Human and machine interfacing

NOTATION

* Languages for writing linguistic models

* Documentation

USAGE

* Embedded systems
* Data processing
* Control
* Expert systems
* Research and development
* Decision support
* Information management

CONTENT AREAS

* Communication skills
* Software development and evolution processes
* Problem analysis and specification
* System design
* Data Engineering
* Software generation
* System quality
* Project management
* Software engineering projects

PROGRAMMING LANGUAGES AND SOFTWARE ENGINEERING

* A programming language is a software engineering tool

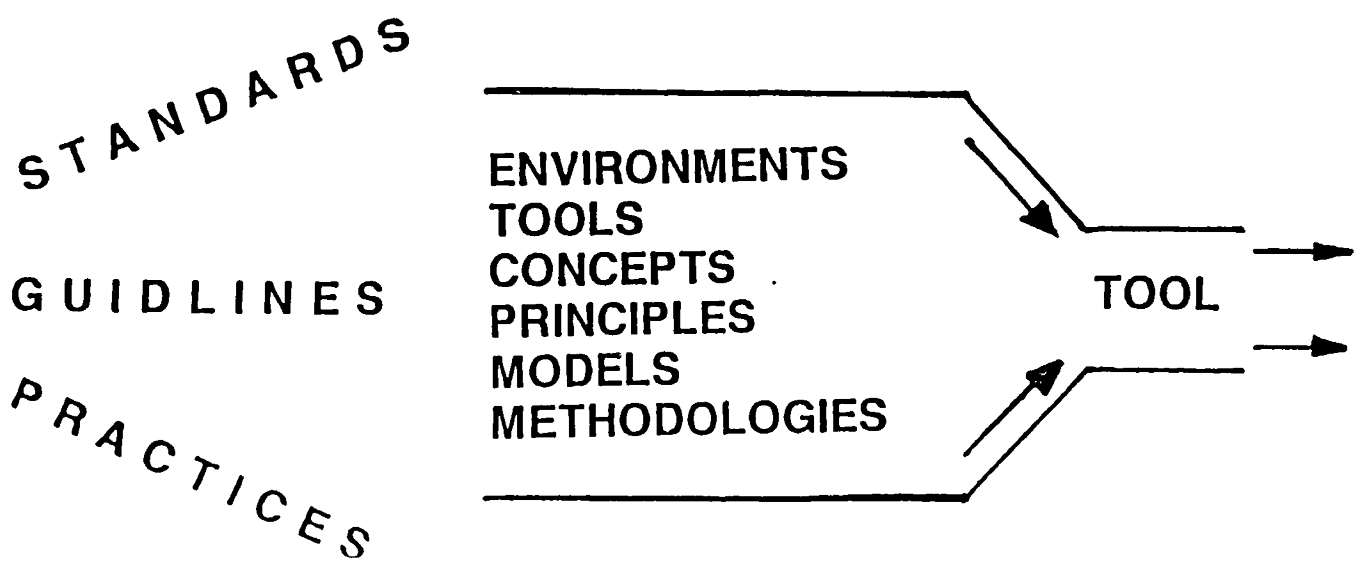
* A programming language EXPRESSES and EXECUTES design methodologies

* The quality of a programming language for software engineering is determined by how well it supports a design methodology and its underlying models, principles, and concepts

TRADITIONAL PROGRAMMING LANGUAGES AND SOFTWARE ENGINEERING

Programming Languages

- Were not engineered
- Have lacked the ability to express good software engineering
- Have acted to constrain software engineering



A PRACTICAL SOLUTION

Ada

Ada and Software Engineering

* They Aren't the Same Thing
* Ada Has Unique Features That Facilitates Software Engineering
* You CAN Write Bad Code in Ada
* Ada is NOT the Total Answer

USAISEC

Ada
AND
SOFTWARE ENGINEERING

Ada

- Was itself "engineered" to support software engineering
- Embodies the same concepts, principles, and models to support methodologies
- Is the best tool (programming language) for software engineering currently available

---

	ENVIRONMENTS	
S T A N D A R D S	TOOLS	T
	CONCEPTS	O
G U I D L I N E S	PRINCIPLES	
	MODELS	O
P R A C T I C E S	METHODOLOGIES	L

LANGUAGE DEVELOPMENT

* Requirements completed before development
* Competitive procurement used for design
* Formal planned test and evaluation phase
* Massive public commentary used
* Design team used
* Strict standardization control

SOFTWARE ENGINEERING

* Goals of Software Engineering
* Principles of Software Engineering

GOALS OF SOFTWARE ENGINEERING

★ MODIFIABILITY

★ RELIABILITY

★ EFFICIENCY

★ UNDERSTANDABILITY

PRINCIPLES OF SOFTWARE ENGINEERING

* Abstraction
* Modularity
* Localization
* Information hiding
* Completeness
* Confirmability
* Uniformity

ABSTRACTION

* The process of separating out the important parts of something while ignoring the inessential details
* Separates the "what" from the "how"
* Reduces the level of complexity
* There are levels of abstraction within a system

MODULARITY

* Purposeful structuring of a system into parts which work together

* Each part performs some smaller task of the overall system

* Can concentrate and develop parts independently as long as interfaces are defined and shared

* Can develop hierarchies of management and implementation

LOCALIZATION

* Putting things that logically belong together in the same physical place

INFORMATION HIDING

* Puts a wall around localized details

* Prevents reliance upon details and causes focus of attention to interfaces and logical properties

COMPLETENESS

* Ensuring all important parts are present
* Nothing left out

CONFIRMABILITY

* Developing parts that can be effectively tested

UNIFORMITY

* No unnecessary differences across a system

FEATURES OF Ada

* Supports Large System Development
* Supports Structured Programming
* Supports Top-Down Development
* Supports Strong Data Typing
* Supports Data Abstraction
* Supports Information Hiding and Data Encapsulation

SYSTEMS ENGINEERING

* Analyze problem

* Break into solvable parts

* Implement parts

* Test parts

* Integrate parts to form total system

* Test total system

REQUIREMENTS FOR EFFECTIVE SYSTEMS ENGINEERING

* Ability to express architecture

* Ability to define and enforce interfaces

* Ability to create independent components

* Ability to separate architecture issues from implementation issues

Overview of Important Ada Features

- Readability
- Program Units
- Separate Compilation
- Subprograms
- Packages
- Strong Typing
- Typing Structures
- Data Abstraction
- Tasks
- Exceptions
- Generics
- Low Level Features

READABILITY

* Ada was engineered with the understanding that programming is a human activity

* Features are provided that allow a maintenance person to quickly grasp the meaning of a particular program and to understand its structure

* Readability is more than just a language issue

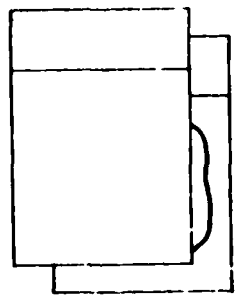
PROGRAM UNITS

* Components of Ada which together form a working Ada software system

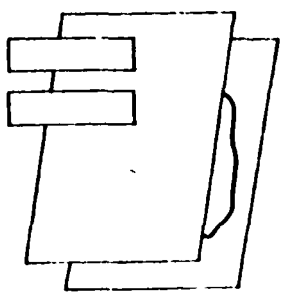
* Express the architecture of a system

* Define and enforce interfaces

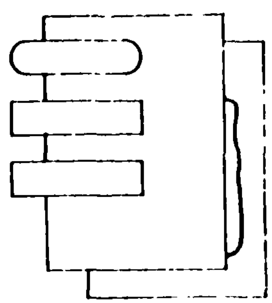
PROGRAM UNITS



SUBPROGRAMS — Working components that perform some action



TASKS — Performs actions in parallel with other program units

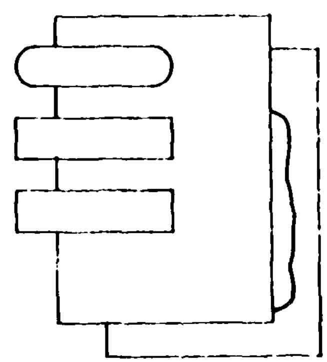


PACKAGES — A mechanism for collecting entities together into logical units

PROGRAM UNITS

* Consist of two parts: specification and body

SPECIFICATION: Defines the interface between the program unit and other program units (the **WHAT**)



BODY: Defines the implementation of the program unit (the **HOW**)

PROGRAM UNITS

* The specification of the program unit is the only means of connecting program units

* The interface is enforced

* The body of a program unit is not accessible to other program units

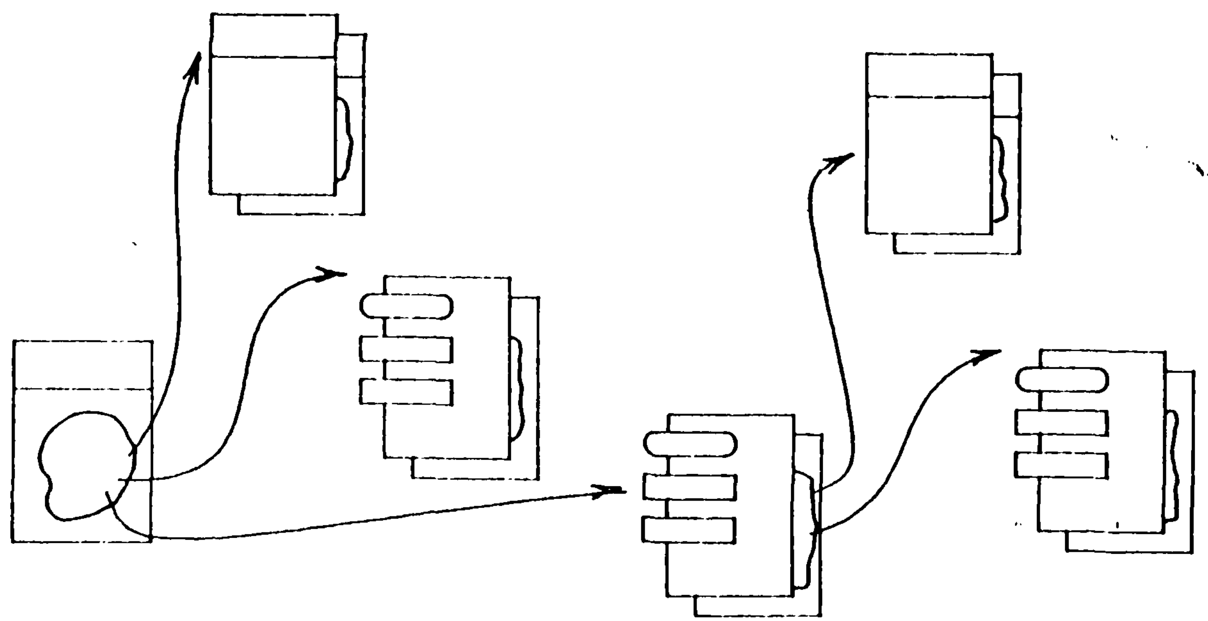
* There is a clear distinction between architecture and implementation

SEPARATE COMPILATION

* Program units may be separately compiled

* Separate compilation is possible because of the separation of specification and body

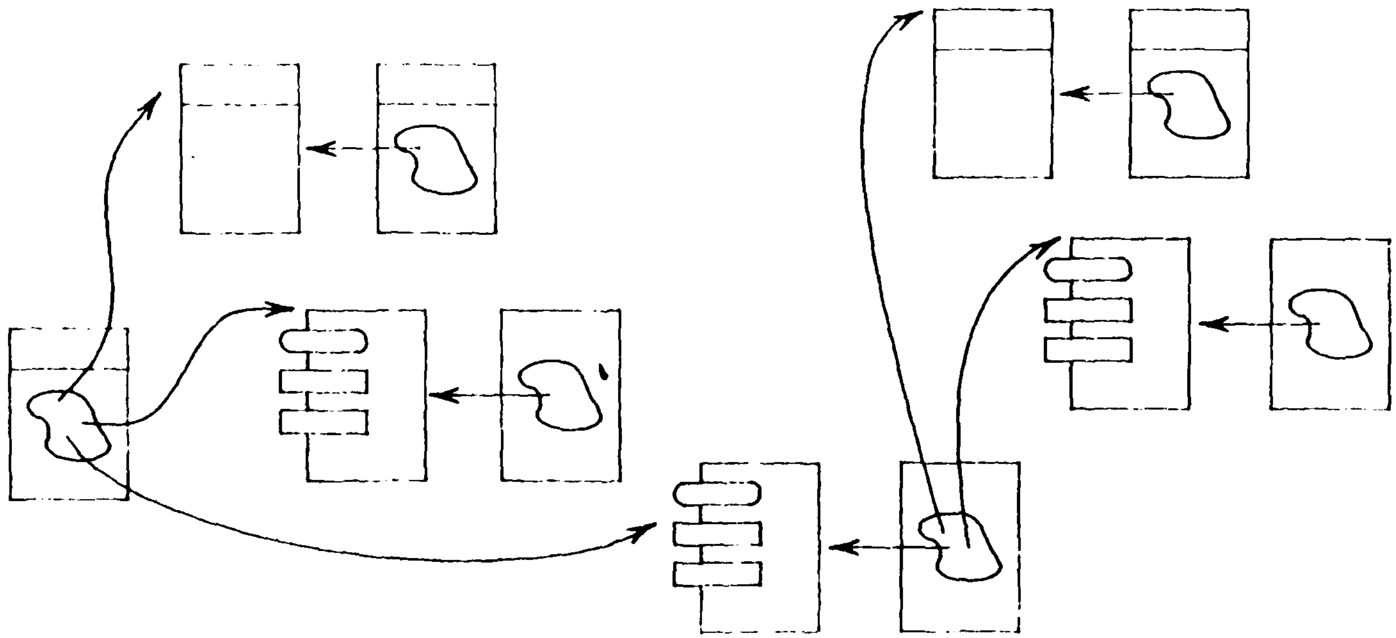
* A system is put together by referencing the specifications of other program units



SEPARATE COMPILATION

* A program unit's specification may be compiled separately from its body

* Realizes not only a logical distinction between architecture and implementation, but also a physical distinction



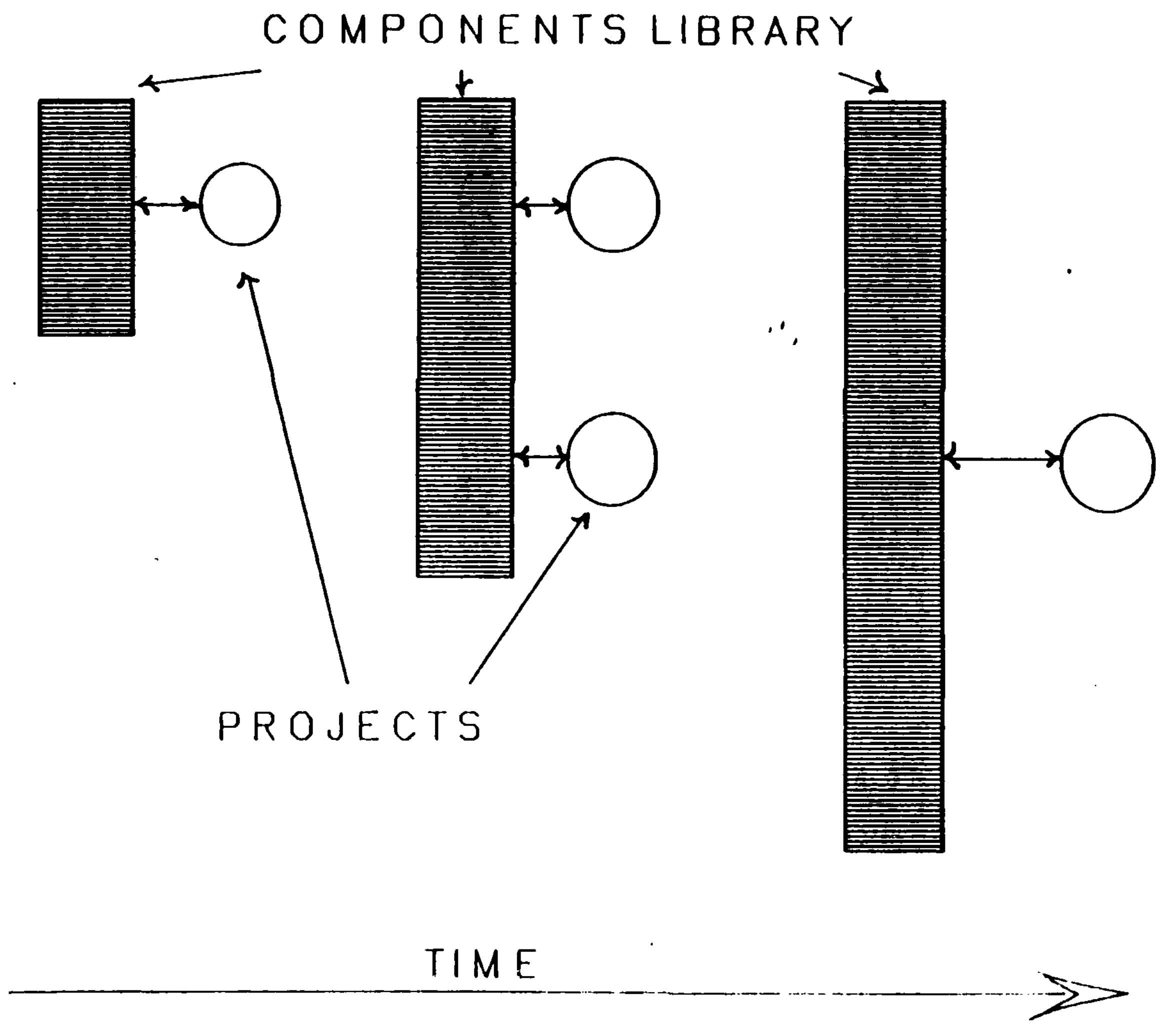
SEPARATE COMPILATION

* Allows development of independent software components

* Currently we all but lose the human effort going into software; it is disposable

* Separate compilation allows us to reuse components and keep our investment

SOFTWARE COMPONENTS



DISCRETE COMPONENTS

* Allow a system to be composed of black boxes

* Provide clear, understandable functions

* Black boxes can be more effectively validated and verified

* Prevalent across engineering disciplines

SUBPROGRAMS

* A program unit that performs a particular action
  - Procedures
  - Functions

* Contains an interface (parameter part) mechanism to pass data to and from the subprogram

* The basic discrete component which acts like a black box

* Gives ability to express abstract actions

MAJOR FEATURES OF Ada

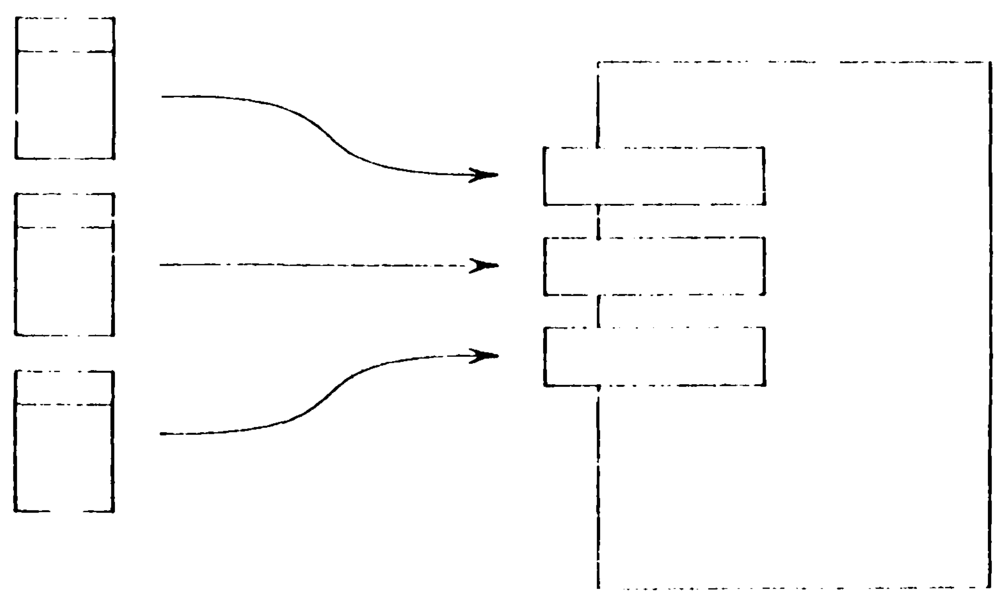
* Packages
* Strong Typing
* Typing Structures
* Data Abstraction
* Tasks
* Exceptions
* Generics

PACKAGES

* Definition
* Components of a Package
    -- Specification
    -- Body
* Goals and Principles of Software Engineering Supported

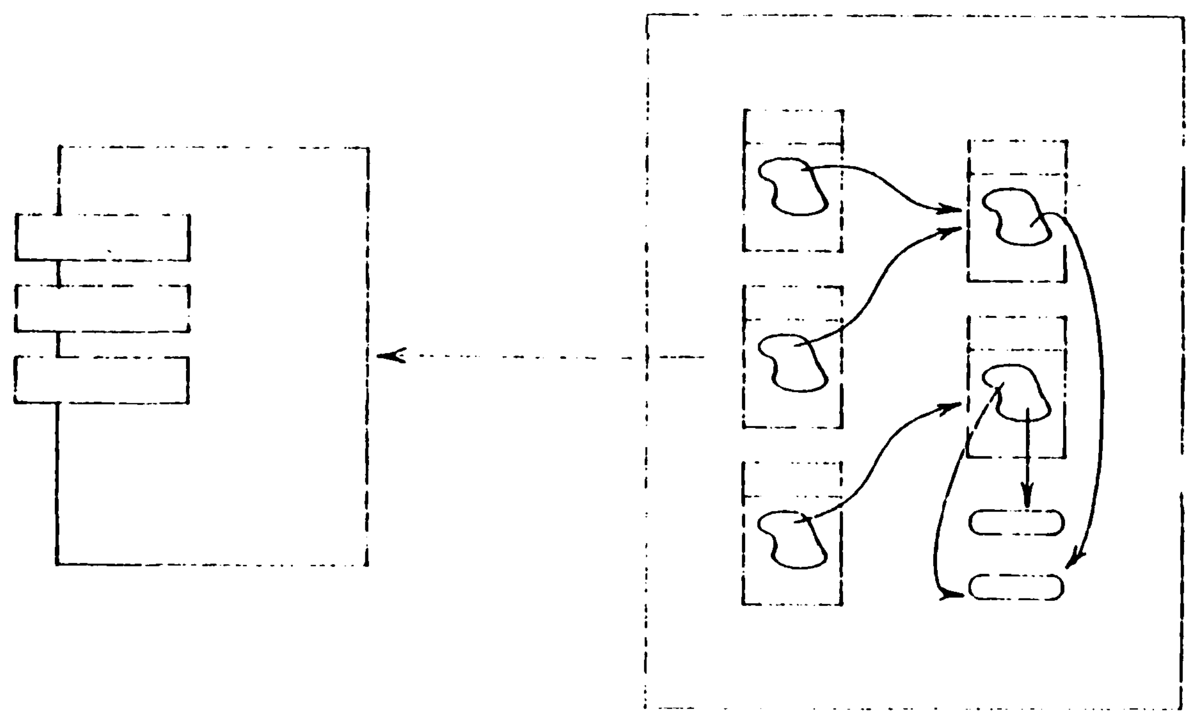
PACKAGES

* Program units that allow us to collect logically related entities in one physical place
* Allow the definition of reusable software components/resources
* A fundamental feature of Ada which allow a change of mindset
* An architecture—oriented feature



PACKAGES

* Place a "wall" around resources
* Export resources to users of a package
* May contain local resources hidden from the user of a package



Program Units

```
package ROBOT_CONTROL is

   type SPEED is range 0..100;
   type DISTANCE is range 0..500;
   type DEGREES is range 0..359;
   procedure GO_FORWARD ( HOW_FAST : in SPEED;
                          HOW_FAR : in DISTANCE );
   procedure REVERSE ( HOW_FAST : in SPEED;
                       HOW_FAR : in DISTANCE );
   procedure TURN ( HOW_MUCH : in DEGREES );

end ROBOT_CONTROL;
```

```
with ROBOT_CONTROL;

procedure DO_A_SQUARE is
begin

    ROBOT_CONTROL.GO_FORWARD( HOW_FAST => 100,
                              HOW_FAR => 20 );
    ROBOT_CONTROL.TURN( 90 );
    ROBOT_CONTROL.GO_FORWARD( 100, 20 );
    ROBOT_CONTROL.TURN( 90 );
    ROBOT_CONTROL.GO_FORWARD( 100, 20 );
    ROBOT_CONTROL.TURN( 90 );
    ROBOT_CONTROL.GO_FORWARD( 100, 20 );
    ROBOT_CONTROL.TURN ( 90 );

end DO_A_SQUARE;
```

Program Units

Package bodies

```
--Define local declarations
--Define implementation of subprograms
-- defined in specification
package body ROBOT_CONTROL is
    --local declarations
    procedure RESET_SYSTEM is
    begin
        --implementation
    end RESET_SYSTEM;
    procedure GO_FORWARD...is...
    procedure REVERSE...is...
    procedure TURN...is...
end ROBOT_CONTROL;
```

PACKAGES

DIRECTLY SUPPORT:

* Abstraction
* Information hiding
* Modularity
* Localization

* Understandability
* Efficiency
* Reliability and safety
* Modifiability
* Correctness

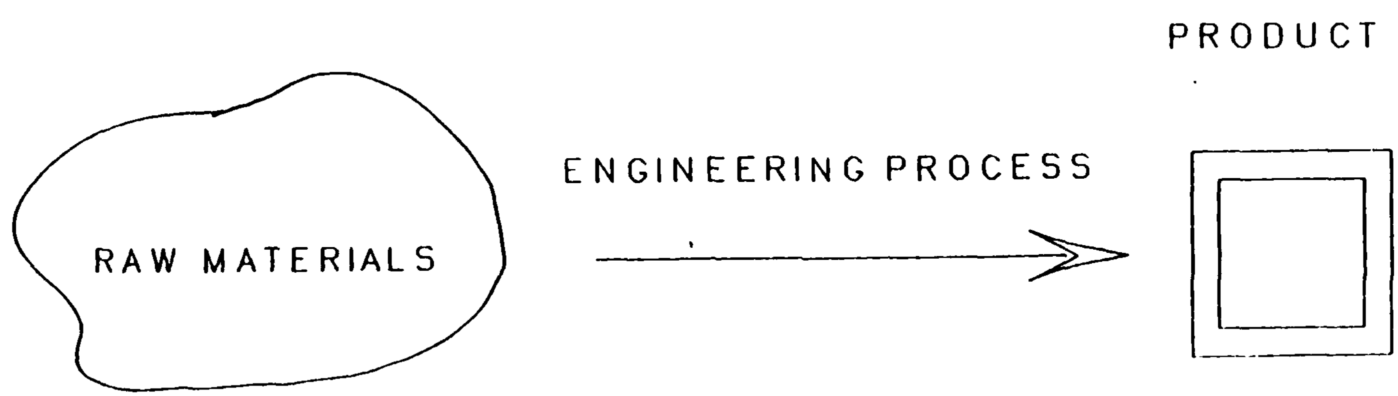
STRONG TYPING

* Raw Materials for Software Engineering
* Effects of Strong Typing
* Goals and Principles of Software Engineering Supported

THE RAW MATERIALS OF ENGINEERING

* All engineering disciplines shape raw materials into a finished product

* The materials and methods combine to define different disciplines



STRUCTURING RAW MATERIALS

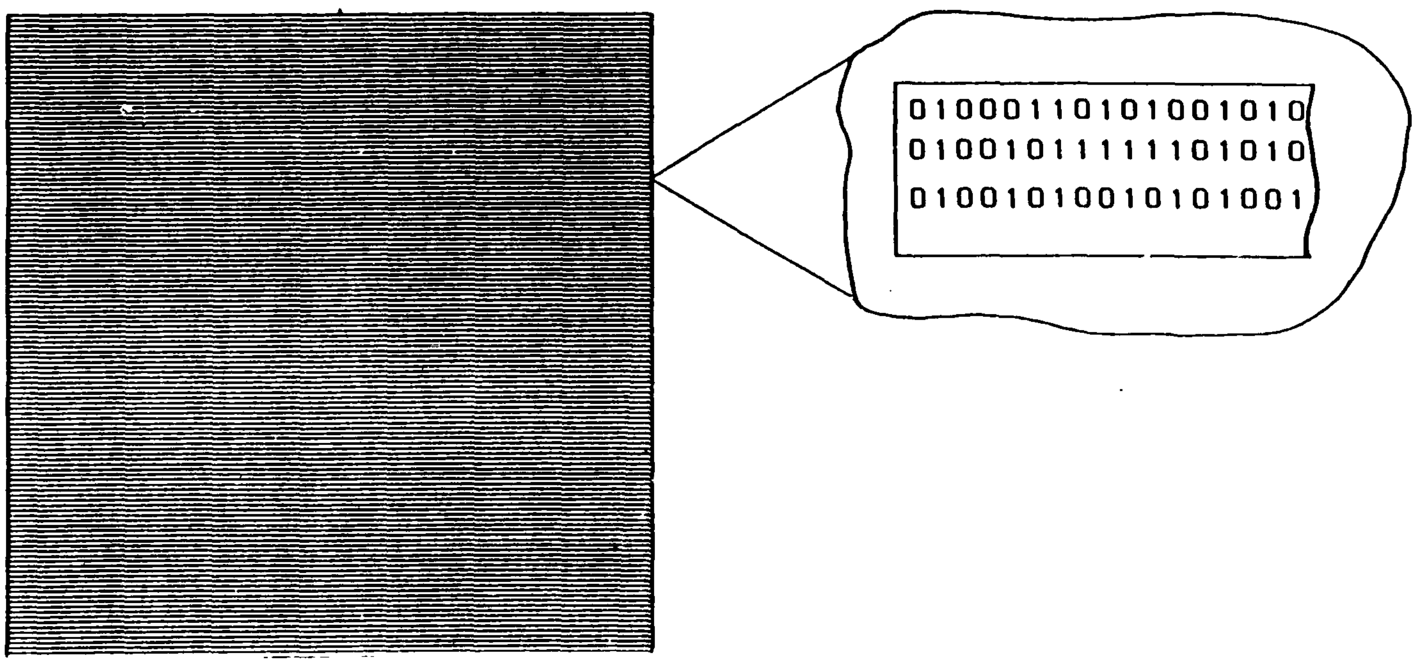
* There is a requirement to structure raw materials

  - To quantify
  - To manage
  - To test
  - To validate

* Methods of structuring vary across disciplines

SOME RAW MATERIALS OF SOFTWARE ENGINEERING

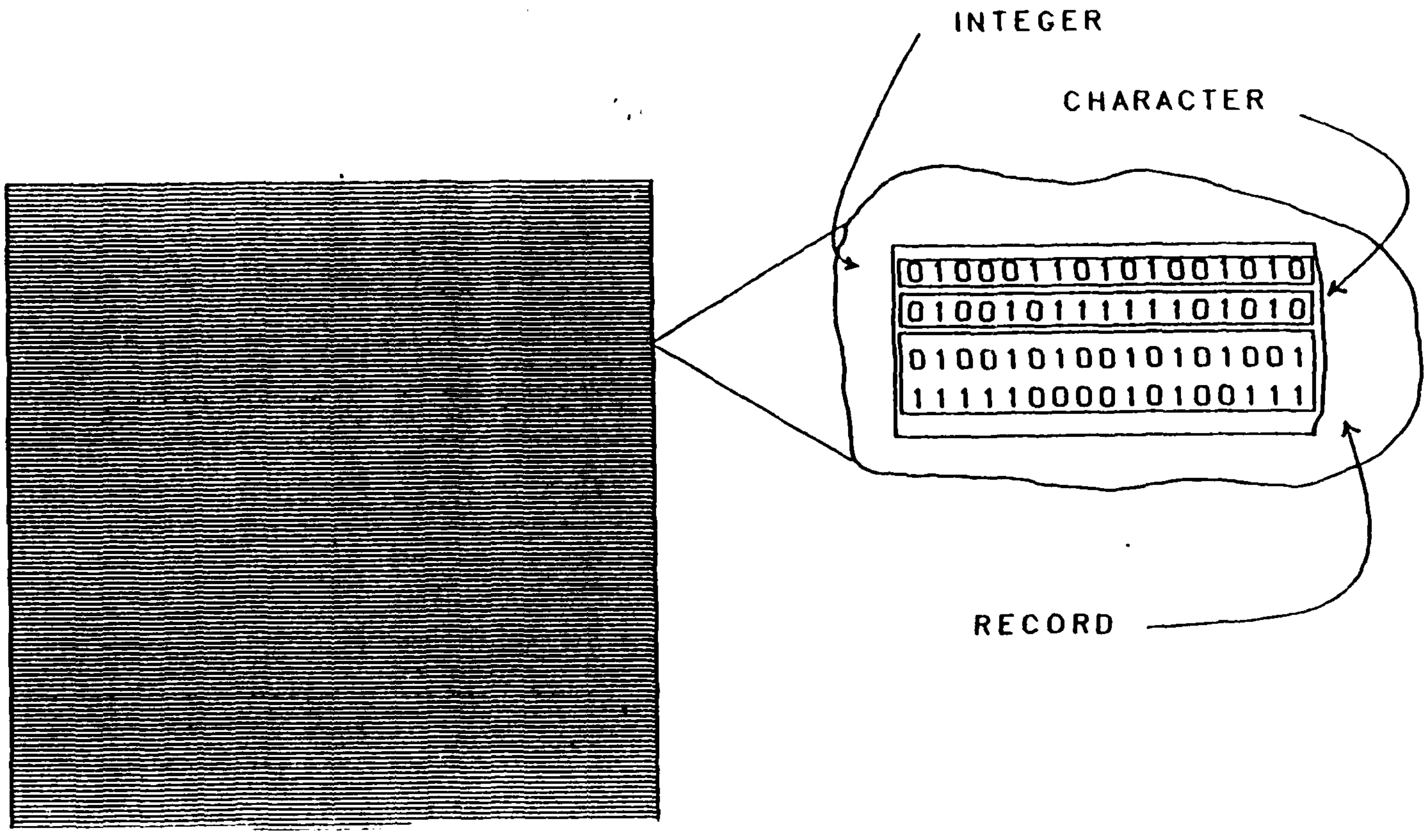
* Binary switches
* Computer memory locations
* Data



STRONG TYPING

* Defines structure of data (mapping)

* Enforces structure of data



STRONG TYPING

* Enforces abstraction of structure on data
* Increases confidence of correctness
* Increases reliability and safety
* Promotes understandability and maintainability

Types

--A type consists of a set of values that objects of the type may take on, and a set of operations applicable to those values

--Ada is a strongly typed language!

*Every object must be declared of some type name
*Different type names may not be implicitly mixed
*Operations on a type must preserve the type

```
AN_INTEGER      : INTEGER;
A_FLOAT_NUMBER  : FLOAT ;
ANOTHER_FLOAT   : FLOAT;

A_FLOAT_NUMBER := ANOTHER_FLOAT + AN_INTEGER;
                  --illegal
```

TYPING STRUCTURES

* Discrete Data Types
  - Enumeration
  - Integer
* Real Data Types
  - Fixed Point (Absolute Error)
  - Floating Point (Relative Error)
* Composite Types
  - Arrays (Homogeneous)
  - Records (Heterogeneous)
* Dynamic Types
  - Access Types
* Abstract Data Types
  - Private
  - Limited Private

TYPING STRUCTURES

* Variety of problems requires a variety of structuring capabilities

* Ada provides a rich variety or types

TYPING STRUCTURES IN Ada

* Discrete data
  - Enumeration
  - Integer

* Real data
  - Fixed point (absolute error)
  - Floating point (relative error)

* Composite data
  - Arrays (homogeneous)
  - Records (heterogeneous)

* Dynamic data
  - Access types

Types

Integers

```
--Define a set of exact, consecutive values
USER DEFINED
        type ALTITUDE is range 0..100_000;
        type DEPTH is range 0..20_000;
        PLANES_HEIGHT : ALTITUDE;
        DIVER_DEPTH : DEPTH;

  begin

     PLANES_HEIGHT := 10_000;
     PLANES_HEIGHT := 200_000;  -- error
     PLANES_HEIGHT := DIVER_DEPTH; -- error
  end;
```

Types

Enumeration

```
--Define a set of ordered enumeration values
--Used in array indexing, case statements,
--   and looping
```

USER DEFINED

```
type SUIT is (CLUBS, HEARTS, DIAMONDS, SPADES);
type COLOR is (RED, WHITE, BLUE);
type SWITCH is (OFF, ON);
type EVEN DIGITS is ('2','4','6','8');
type MIXED is (ONE,'2',THREE,'*','!',more);
```

```
where CLUBS < HEARTS < DIAMONDS < SPADES
       (pos 0)  (pos 1)   (pos 2)    (pos 3)
```

Types

Fixed point types

-- Absolute bound on error
-- Larger error for smaller numbers (around zero)

USER DEFINED

```
type INCREMENT is delta 1.0/8 range 0.0 .. 1.0;
```

0, 1*2e-3, 2*2e-3, 4*2e-3, 5*2e-3,...

PREDEFINED

DURATION --> (Used for "delay" statements)

Types

Floating point types

-- Relative bound of error
-- Defined in terms of significant digits
-- More accurate at smaller numbers, less at larger

USER DEFINED

```
type NUMBERS is digits 3 range 0.0 .. 20_000;
```

0.001, 0.002, 0.003...999.0,1000.0,1001.0...,10000.0,10100.0

PREDEFINED

FLOAT

Types

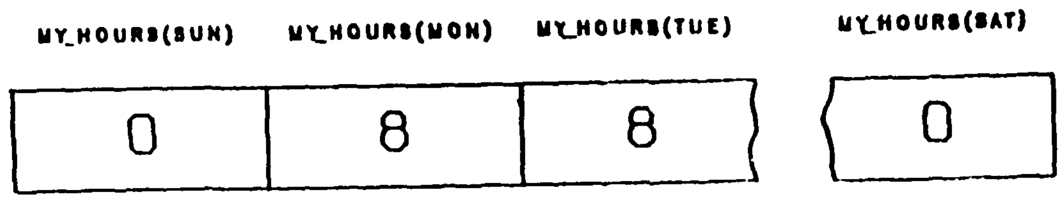
Arrays — constrained / unconstrained

CONSTRAINED

```
-- Indices are static for all objects of that type

type HOURS is range 0..40;
type DAYS is ( SUN,MON,TUE,WED,THU,FRI,SAT );
type WORK_HOURS is array( DAYS ) of HOURS;

MY_HOURS : WORK_HOURS := ( 0,8,8,7,6,1,0 );
```



Types

Records

undiscriminated
discriminated
variant

UNDISCRIMINATED

```
type DAYS is ( MON,TUE,WED,THU,FRI,SAT,SUN );
type DAY is range 1..31;
type MONTH is (JAN,FEB,MAR,APR,MAY,JUN,JUL,AUG,
               SEP,OCT,NOV,DEC);
type YEAR is range 0..2085;
type DATE is record
   DAY_OF_WEEK : DAYS;
   DAY_NUMBER : DAY;
   MONTH_NAME : MONTH;
   YEAR_NUMBER : YEAR;
end record;
TODAY : DATE;
begin
  TODAY.DAY_OF_WEEK := TUE;
  TODAY.DAY_NUMBER := 26;
  TODAY.MONTH_NAME := NOV;
```

	TODAY
DAY_OF_WEEK	TUE
DAY_NUMBER	26
MONTH_NAME	NOV
YEAR_NUMBER	1985

DATA ABSTRACTION

* Definition
* Goals and Principles of Software Engineering Supported
* Baskin-Robbins Ice Cream Example

DATA ABSTRACTION

* Combines primitive raw materials to form higher level structures
* Levels of abstraction
* Enforces an abstraction on a higher level structure
* Prohibits use of implementation details
* Promotes understandability
* Promotes modifiability

DATA ABSTRACTION AND PRIVATE TYPES

* Private types directly implement data abstraction

* Directly implement information hiding

```
package B_R is

    type NUMBERS is range 0 .. 9;

    procedure TAKE ( A_NUMBER : out NUMBERS );

    function NOW_SERVING return NUMBERS;

    procedure SERVE ( NUMBER : NUMBERS );

end B_R;
```

```
with B_R; use B_R;
procedure ICE_CREAM is
   YOUR_NUMBER : NUMBERS;
begin

   TAKE ( YOUR_NUMBER );
   loop
      if NOW_SERVING = YOUR_NUMBER then
         SERVE ( YOUR_NUMBER );
         exit;
      end if;
   end loop;

end ICE_CREAM;
```

```
with B_R; use B_R;
procedure ICE_CREAM is

   YOUR_NUMBER : NUMBERS;

begin
   TAKE ( YOUR_NUMBER );
   loop
     if NOW_SERVING = YOUR_NUMBER then
       SERVE ( YOUR_NUMBER );
       exit;
     else
      YOUR_NUMBER := YOUR_NUMBER - 1;
     end if;
   end loop;

end ICE_CREAM
```

```
package B_R is

   type NUMBERS is private;

   procedure TAKE ( A_NUMBER : out NUMBERS );
   function NOW_SERVING return NUMBERS;
   procedure SERVE ( NUMBER : in NUMBERS );

private

   type NUMBERS is range 0..99;

end B_R;
```

```
with B_R; use B_R;
procedure ICE_CREAM is

  YOUR_NUMBER : NUMBERS;

begin

  TAKE ( YOUR_NUMBER );
  loop

    if NOW_SERVING = YOUR_NUMBER then
      SERVE ( YOUR_NUMBER );
      exit;
    else
      YOUR_NUMBER := NOW_SERVING;
    end if;
  end loop;

end ICE_CREAM;
```

```
package B_R is

   type NUMBERS is limited private;

   procedure TAKE ( A_NUMBER : out NUMBERS );
   function NOW_SERVING return NUMBERS;
   procedure SERVE ( NUMBER : in NUMBERS );
   function "=" ( LEFT, RIGHT : in NUMBERS ) return
                                               BOOLEAN;

private

   type NUMBERS is range 0..99;

end B_R;
```

```
with B_R; use B_R;
procedure ICE_CREAM is

   YOUR_NUMBER : NUMBERS;
   procedure GO_TO_DQ is separate;

begin
   TAKE ( YOUR_NUMBER );
   loop
      if NOW_SERVING = YOUR_NUMBER then
         SERVE ( YOUR_NUMBER );
         exit;
      else
         GO_TO_DQ;
         exit;
      end if;
   end loop;

end ICE_CREAM;
```

TASKS

* Definition
* Goals and Principles of Software Engineering Supported
* Example

TASKS

* Program unit that acts in parallel with other entities

* Directly implements those parts of embedded systems which act in parallel

* Takes advantage of move toward parallel hardware architectures

  - Fault tolerance
  - Distributed systems

* Elimina[illegible] tional [illegible]

Tasks

```
procedure SENSOR_CONTROLLER is

    function OUT_OF_LIMITS return BOOLEAN;
    procedure SOUND_ALARM;


    task MONITOR_SENSOR; -- specification
    task body MONITOR_SENSOR is  -- body
    begin
          loop
             if OUT_OF_LIMITS then
                SOUND_ALARM;
             end if;
          end loop;
    end MONITOR_SENSOR;

    function OUT_OF_LIMITS return BOOLEAN is separate;
    procedure SOUND_ALARM is separate;
begin
   null; -- Task is activated here
end SENSOR_CONTROLLER;
```

Tasks

```
-- a basic task with no communication
 with TEXT_IO; use TEXT_IO;
 procedure COUNT_NUMBERS is
       package INT_IO is new INTEGER_IO (INTEGER);
       use INT_IO;
       task COUNT_SMALL;
       task COUNT_LARGE;

       task body COUNT_SMALL is
       begin
            for INDEX in -100..0 loop
                 PUT(INDEX);
                 NEW_LINE;
             end loop;
         end COUNT_SMALL;

         task body COUNT_LARGE is
         begin
              for INDEX in 0..100 loop
                   PUT(INDEX);
                   NEW_LINE;
                end loop;
            end COUNT_LARGE;

    begin
       null;  --tasks are started here
    end COUNT_NUMBERS;
```

EXCEPTIONS

* Definition

* Goals and Principles of Software Engineering Supported

* Types of Exceptions in Ada

  -- Pre-defined Exceptions

  -- User-defined Exceptions

* Example

SOFTWARE RELIABILITY AND SAFETY

* Errors will occur
  - Hardware
  - Software

* Real time systems must be able to operate in a degraded mode

* Reliablity and safety must be engineered into a system

* Traditional languages lack specific features for dealing with errors and exceptional situations

EXCEPTIONS

* Deal specifically with errors and exceptional situations

* When an exception is raised processing is suspended and control is passed to an appropriate exception handler

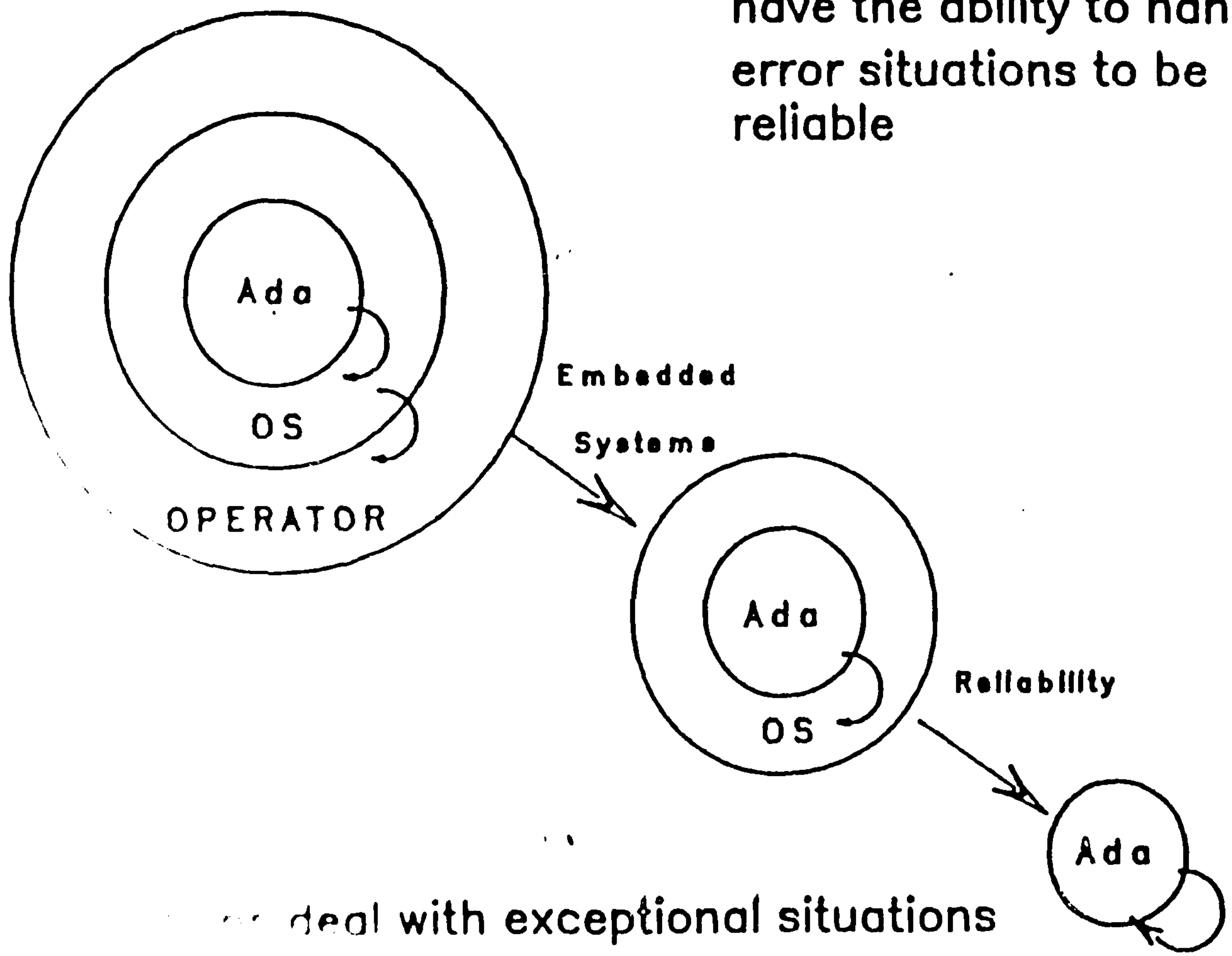
  - Try again
  - Fix error
  - Propogate exception

* Increase reliability

* Reduce complexity

Exceptions

-- Real time systems must have the ability to handle error situations to be reliable



-- deal with exceptional situations

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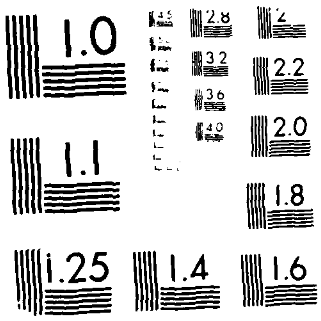
UNCLASSIFIED   F/G 12/5   NL



MICROCOPY RESOLUTION TEST CHART

Exceptions

-- When an exception situation occurs, the exception is said to be "raised"

-- What happens then, depends on the presence or absence of an exception handler

```
begin
  loop
    GET ( A_NUMBER );
    NEW_LINE;
    PUT("The number is");
    PUT ( A_NUMBER );
    NEW_LINE;
  end loop;
end GET_NUMBERS;
```

Exceptions

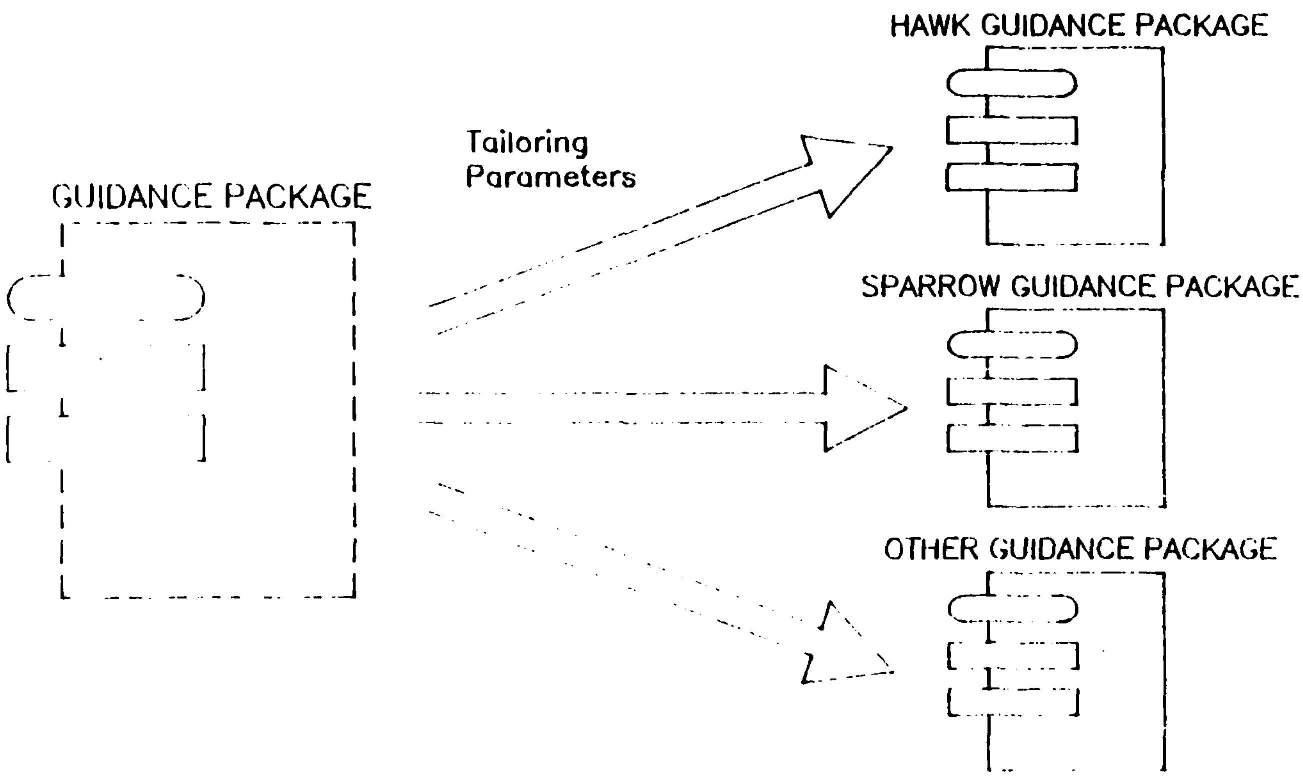
```
begin
  loop
    begin
      GET ( A_NUMBER );
      NEW_LINE;
      PUT ( "The number is ");
      PUT ( A_NUMBER );
      NEW_LINE;
    exception
      when DATA_ERROR => PUT_LINE("Bad number, try again");
    end;
  end loop;
end GET_NUMBERS;
```

GENERICS

* Definition
* Goals and Principles of Software Engineering Supported
* Example of Generic Unit Use

GENERICS

- A generic is a tailorable template for a program unit
- Increases reusable software component capability by an order of magnitude



GENERICS

* Reduce size of program text

* Reduce need to reinvent the wheel

* Increase reliability by allowing reuse of known reliable components

Generics

```
procedure INTEGER_SWAP (FIRST_INTEGER, SECOND_INTEGER:
                        in out INTEGER) is

      TEMP : INTEGER;

begin

      TEMP           := FIRST_INTEGER;
      FIRST_INTEGER  := SECOND_INTEGER;
      SECOND_INTEGER := TEMP;

end INTEGER_SWAP;
```

Generics

```
generic
     type ELEMENT is private;
procedure SWAP (ITEM_1,ITEM_2:in out ELEMENT);

procedure SWAP(ITEM_1,ITEM_2:in out ELEMENT) is
     TEMP:ELEMENT;
begin
     TEMP := ITEM_1;
     ITEM_1 := ITEM_2;
     ITEM_2 := TEMP;
end SWAP;
```

Generics

```
with SWAP;
procedure EXAMPLE is
  procedure INTEGER_SWAP is new SWAP(INTEGER);
  procedure CHARACTER_SWAP is new SWAP(CHARACTER);
  NUM_1, NUM_2 : INTEGER;
  CHAR_1, CHAR_2 : CHARACTER;
begin
  NUM_1 := 10;
  NUM_2 := 25;
  INTEGER_SWAP(NUM_1, NUM_2 );
  CHAR_1 := 'A';
  CHAR_2 := 'S';
  CHARACTER_SWAP(CHAR_1, CHAR_2);
end EXAMPLE;
```

SUMMARY

* Basic Problem

  -- Projection to the 1990's

  -- A Macro Solution

* A Practical Solution

  -- Software Engineering

  -- Ada

* Software Engineering

  -- Goals

  -- Principles

* Why Ada ?

  -- Features of Ada

  -- Software Engineering
     Applications

PACKAGES

DIRECTLY SUPPORTS:

* ABSTRACTION
* MODULARITY
* LOCALIZATION
* INFORMATION HIDING
  UNIFORMITY
* COMPLETENESS
* CONFIRMABILITY

* MODIFIABILITY
* RELIABILITY
* EFFICIENCY
* UNDERSTANDABILITY

TYPING

DIRECTLY SUPPORTS:

ABSTRACTION
MODULARITY
LOCALIZATION
INFORMATION HIDING
UNIFORMITY
* COMPLETENESS
* CONFIRMABILITY

* MODIFIABILITY
* RELIABILITY
* EFFICIENCY
* UNDERSTANDABILITY

DATA ABSTRACTION

DIRECTLY SUPPORTS:

* * ABSTRACTION
  MODULARITY
  LOCALIZATION
* * INFORMATION HIDING
  UNIFORMITY
* * COMPLETENESS
  CONFIRMABILITY

* * MODIFIABILITY
* * RELIABILITY
  EFFICIENCY
* * UNDERSTANDABILITY

EXCEPTIONS

DIRECTLY SUPPORTS:

ABSTRACTION
* MODULARITY
* LOCALIZATION

INFORMATION HIDING
* UNIFORMITY
* COMPLETENESS
* CONFIRMABILITY

MODIFIABILITY
* RELIABILITY
* EFFICIENCY
* UNDERSTANDABILITY

TASKS

DIRECTLY SUPPORTS:

* ABSTRACTION
* MODULARITY
LOCALIZATION
* INFORMATION HIDING
UNIFORMITY
* COMPLETENESS
* CONFIRMABILITY

MODIFIABILITY
* RELIABILITY
* EFFICIENCY
* UNDERSTANDABILITY

GENERICS

DIRECTLY SUPPORTS:

* ABSTRACTION
* MODULARITY
* LOCALIZATION
  INFORMATION HIDING
* UNIFORMITY
* COMPLETENESS
* CONFIRMABILITY

* MODIFIABILITY
* RELIABILITY
* EFFICIENCY
* UNDERSTANDABILITY

Ada Generics

Part of the

Advanced Ada Workshop

Sponsored by the

Ada Software Engineering Education & Training Team

(ASEET)

John Bailey

Software Metrics, Inc.

703-533-8300

jbailey at Ada20

18 August 1987

Outline

1. Rationale
   - Are generics really necessary in Ada?
   - What can they do?

2. Syntax and Semantics
   - Generic parameters
   - Instantiation
   - Compared with other Ada units

3. Examples
   - See how simple they can be.
   - See how useful they can be.
   - See how complicated they can be.

4. Limitations
   - Some generalization is not easy.
   - Some generalization is not possible.

5. Advanced Usage
   - Retrofitting generics
   - Generalization judgement calls

1. Rationale

Are generics really necessary?

Ada language goals:

- Encapsulation of processing desired
- Encapsulation of resources (objects) desired
- User-defined types desired
- Strong, static type checking desired
- Unnecessary language features not desired
- Reusability desired

Other languages answer some of these goals, but not all.

Fortran

- Encapsulation of processing supported
- Encapsulation of resources (mostly)
- No user-defined types
- No static type checking
- I/O routines part of language definition
- Some reusability support

Pascal

- Encapsulation of processing supported
- No encapsulation of resources
- User-defined types
- Strong, static type checking (with loopholes)
- I/O routines part of language definition
- No reusability support

Smalltalk

- Encapsulation of processing supported
- Encapsulation of resources supported
- User-defined types supported
- No static type checking
- Only primitive I/O language-defined
- Excellent reusability support

Generics Are Solution

Some of the above goals appear to be in conflict:

- Reusability vs. Strong static type checking -- ?

```
type User_Type is new Integer;
procedure Increment (X : in out User_Type) is
begin
        X := X + 1;
end Increment;
```

Cannot reuse Increment anywhere else.

- Strong checking vs. Minimal language -- ?

```
type User_Type is new Integer;
X : User_Type;
I : Integer;
Put (X);            -- for strong checking, these
Put (I);            -- must be distinct "Put's"
```

Pascal solves this with "magic" I/O procedures
- extended language

```
Write (X);
Write (I);
Write (X, I);
Write ('The answer is ', X, ' or ', I);
```

Smalltalk provides primitive I/O with each new type
Might not be wanted.
Does not provide static checking
This allows great flexibility but can lead to runtime errors that could have been avoided by compilation-time checking

The Case for Generics

Ada generics allow excellent compromise

Minimal additional complexity

Encapsulation of processing
    Generic subprograms

Encapsulation of resources (objects)
    Generic packages

User-defined types desired
Strong, static type checking desired

Unnecessary language features avoided
    I/O not part of language (rather, part
    of the standard environment)

Reusability supported
    Reasonable flexibility
    Capability to separate essential detail
        of an algorithm or object from
        problem-specific detail

(Hint: that last point is the essence of generic programming)

What can Generics Do?

Consider the rationale for programming anything:

A programmed solution:
- Generalizes over several occurrences
- Appropriate if similar processing,
  but with varying values

Typical programs contain:

- Conceptual "chunks" related to the general problem class:
  - Algorithms
  - Objects or classes of objects
- Details about the specific problem
  - Specific types
  - Specific routines, such as error recovery
  - Specific data flow designs
- At run time, a specific case is handled
  - Values specific to a given run are used
  - Same program is "reused" with next set of values

Likewise, generic programming uses:

- Conceptual chunks, object classes
- Problem-specifics
- Run-time specifics

Traditional Programming - Diagram

Algorithms, Objects, Resources

- - intertwined with - -

Problem-specific declarations

```
package Useful_Object is

        type Specific_Type is (Something_or_other);

        procedure Do_Something (To : Specific_Type);

        function Status_Of (An_Object_Of : Specific_Type)
                return Predefined_Type_Perhaps;

end Useful_Object;
```

Generic Programming - Diagram

application-domain algorithms

application-domain object classes

- - - - - - - - - - - - - - -

problem-specific declarations

problem-specific processing

instantiations of the application-domain chunks (above the dashed line)

```
generic

        type Formal_Type is private;

package General_Object is

        procedure Do_Something (To :  Formal_Type);

        function Status_Of (An_Object_Of :  Formal_Type)
               return Predefined_Type_Perhaps;

end General_Object;

- - - - - - - - - - -

type Specific_Type is (Something_or_other);

package Useful_Object is new
        General_Object (Specific_Type);
```

Another Quick Example

Frequently, the following occurs in Ada programs:

```
package Global_Types is
        type Useful is (This, That, The_Other);
end Global_Types;


with Global_Types;
package Service is
        procedure Operation
                (On : Global_Types.Useful);
end Service;


with Global_Types;
with Service;
procedure User is
        My_Object : Global_Types.Useful;
begin
        Service.Operation (My_Object);
end User;
```

Cannot separately use Service without also using Global_Types due to visibility requirements.

Alternative, Equivalent Program

```
package Global_Types is
        type Useful is (Whatever);
end Global_Types;


  -- no context clause
generic
        type Formal is private;
package General_Service is
        procedure Operation (On : Formal);
end General_Service;


with Service;
with Global_Types;
procedure User is
        My_Object : Global_Types.Useful;
        package Service is new
                General_Service (Global_Types.Useful);
begin
        Service.Operation (My_Object);
end User;
```

Now, General_Service can be reused without Global_Types.

Just as a program becomes a specific case for a given run, a generic program is instantiated into a specific case for a given program.

Another Reason Generics are Unavoidable

With only predefined types, reusability is simplified:

```
function Math_Operation (X : Real) return Real;
```

If users only have type Real for floating point,
the above function is always usable

However:

Ada allows user-defined types, such as:

```
type Low_Precision is digits 3;
type High_Precision is digits 7;
```

And, Ada requires strong static type checking, so
if Math_Operation were needed for both of
the above types, two functions would be needed:

```
function Math_Operation (X : Low_Precision)
    return Low_Precision;

function Math_Operation (X : High_Precision)
    return High_Precision;
```

Generics solve this problem:

```
generic
    type Real is digits <>;
function Math_Operation (X : Real) return Real;
```

Analogy with Programming

Typical programming:

A programmed solution can be written once and "used' several times. The following motivate the creation of a programmed solution:

Reusability:
Similar processing will be required repeatedly.

Reliability:
Testing and verification can be performed to help ensure all runs will be correct.

Readability:
By allowing variables to stand for specific values during run time, the program can be understood in the abstract.

Maintainability:
Making a change in the program will apply to all usages.

Generic Programming:

All the same arguments can be applied to generic programming.

Reusability:
Similar program components needed repeatedly, but different enough to preclude run time parameterization.

Reliability:
A properly tested generic need not be retested each time it is used.

Readability:
By supressing problem-specific detail the higher-level concept can be understood.

Maintainability:
By helping to avoid repetition, the (hopefully single) location where a change is required is easier to determine.

Simplified View

Just as types are templates for describing objects,

Generics are merely templates for other program units.

Generic packages

Generic subprograms
- Generic procedures
- Generic functions

There are no generic tasks
- a task is already an object of a type.
- a generic package can contain a task

A generic (template) is instantiated by a declaration just as an object is an "instance" of a type (template).

This instantiation is accomplished by the compiler, and not (necessarily) at run time.

The effect of Ada generics can be obtained through editor-like substitution (but this is not the smartest implementation of them)

Sometimes likened to assembly language Macros.

Simple Examples

If you can write an Ada package, procedure, or function
(you can, can't you?)
then you can write an Ada generic:

```
procedure Easy is
begin
      Text_Io.Put_Line ("pie");
end Easy;

-- a call to Easy:
Easy;
```

Generic version:

```
generic
procedure Easy is
begin
      Text_Io.Put_Line ("pie");
end Easy;

-- first an instantiation:
procedure Easy_Instance is new Easy;

-- then a call:
Easy_Instance:
```

Note the need to instantiate first, then treat as a regular procedure.

The above generic is a trivial case with no parameters.

It's possible (but not too likely) that such a simple generic might be useful.

The preceeding example must have been in the scope of package Text_Io.

Or, it could have been a library unit with its own context clause:

```
with Text_Io;
generic
procedure Easy is
begin
    Text_Io.Put_Line ("pie");
end Easy;
```

Generics are one of the possible library units.

Recalling the Ada grammar:

Library_Unit ::=

subprogram_declaration

package_declaration

generic_declaration

generic_instantiation

subprogram_body

Note that a generic instantiation can also be a library unit.

Given the foregoing, the following two lines also form a library unit:

```
with Easy;
procedure Easy_Instance is new Easy;
```

And a user could be:

```
with Easy_Instance;
procedure User is
begin
    Easy_Instance;
end User;
```

Resulting in "pie" being printed.

These trivial cases should illustrate the hidden simplicity in the declaration and use of Ada generics.

More Useful Example

Normally, one or more parameters would be used
to allow a variety of instances to be declared.

```
generic
        Prompt : String := "A>";
procedure Issue_Prompt;

with Text_Io;
procedure Issue_Prompt is
begin
        Text_Io.Put (Prompt);
end Issue_Prompt;
```

Note, the context clause could have preceeded the spec but it isn't needed until the body.

Note that the separate spec and body is Required with generic subprograms, unlike regular subprograms.

The following is Not allowed:

```
with Text_Io;
generic
        Prompt : String := "A>";
procedure Issue_Prompt is
begin
        Text_Io.Put (Prompt);
end Issue_Prompt;
```

Instantiations

The above could be instantiated with the following:

```
with Issue_Prompt;
with Text_Io;
function User_Reply return String is
        procedure Prompt is new
                Issue_Prompt ("What is your wish? ");
        Buffer : String (1..80);
        Length: Natural;
begin
        Prompt;
        Text_Io.Get_Line (Buffer, Length);
        return Buffer (1..Length);
end User_Reply;
```

```
with Issue_Prompt;
with Text_Io;
function User_Reply (To_Question: String := "")
        return String is
        procedure Prompt is new
                Issue_Prompt (To_Question);
        Buffer : String (1..80);
        Length: Natural;
begin
        Prompt;
        Text_Io.Get_Line (Buffer, Length);
        return Buffer (1..Length);
end User_Reply;
```

Continued...

```
Resp1 : constant String := User_Reply;  --what's wrong?

Resp2 : constant String := User_Reply ("Why? ");

Resp3 : constant String := User_Reply;
```

```
What is your wish? __

Why? __

A> __
```

Another Example

Generic formal type parameter (any floating point type) followed by an object parameter of that type:

```
generic
        type Real is digits <>;
        Max : Real := Real'Last;
procedure Useless;

procedure Useless is
        Local : Real := Max / 2.0;
begin
        if Real'Last > Max then
                Local := Real'Last / 2.0;
        end if;
end Useless;



with Useless;
procedure Useless_User is
        type Coarse is digits 3;
        procedure Zip is new Useless
                (Real => Coarse,
                 Max => 10.0);
        procedure Zap is new Useless (Coarse);
        procedure Zot is new Useless (Float, -1.0);
begin
        Zip;
end Useless_User;
```

Object Parameters - Detail

As with subprogram parameters, generic formal parameters can have modes:

Mode in is the default.

```
generic
        Obj1 : Integer;
        Obj2 : in Integer;
procedure Testing;

procedure Testing is
begin
        Obj1 := Obj2;  -- no!
end Testing;
```

In Parameters

Mode In parameters act as constants.

Mode In parameters are passed values (as with In parameters of subprograms).

```
with Testing;
procedure Test is
    X, Y : Integer := 29;
    procedure Fee is new Testing (3 + X, 7);
    procedure Fie is new Testing (X, Y);
begin
    Fee;
end Test;
```

Mode In parameters are given values as in assignment (unlike subprogram In parameters - see later).

```
with Testing;
procedure Test is
    X : Integer;    -- unitialized
    procedure Bomb is new Testing (X, X);
begin
    Bomb;  -- erroneous
end Test;
```

Default Evaluation

Defaults are evaluated at time of instantiation
(Not at time of elaboration of generic)

```
package Declaration_Shell is

    function Num return Integer;

    generic
        Val : Integer := Num;
    procedure Demo;

end Declaration_Shell;

package body Declaration_Shell is

    Local : Integer := 0;

    function Num return Integer is
    begin
        Local := Local + 1;
        return Local;
    end Num;

    procedure Demo is separate;

end Declaration_Shell;

with Text_Io;
separate (Declaration_Shell)
procedure Demo is
begin
    Text_Io.Put_Line (Integer'Image (Val));
end Demo;
```

So, . . .

```
with Declaration_Shell;
procedure Show is

        procedure Demo is
                new Declaration_Shell.Demo;

        procedure Demo1 is
                new Declaration_Shell.Demo;

begin
        Demo;
        Demo1;
end Show;
```

output:

```
        1
        2
```

Not:

```
        1
        1
```

Mode in out

Mode in out parameters must be passed variables, not values (same as in out subprogram parameters)

Formal objects of mode in out are aliases for their actual counterparts.

Can be confusing - and is usually *not* recommended.

The evaluation of the variable represented by a name supplied as the actual parameter to an in out generic formal object parameter occurs *once*

Therefore, if some expression in the name evaluation changes after the instantiation, no change is made to the object represented by the formal name.

Test your knowledge!

```
declare

        Y : array (1..5) of Character := "kitty";

        Index : Integer := 1;

        generic
                X : in out Character;
        procedure Gen;

        procedure Gen is
        begin
                Index := 5;
                X := 'w';
                Put (String (Y) );
        end;

        procedure P is new Gen (Y (Index) );

begin
        P;
end;
```

What would happen if the object passed depended on the value of a discriminant?

Is this Reasonable?

```
declare
        type Furniture is (Bed, Couch, Table);
        type Style (F : Furniture := Bed) is record
                case F is
                        when Bed =>
                                Four_Poster : Boolean;
                        when Couch =>
                                Convertible : Boolean;
                        when Table =>
                                Legs : Integer;
                end case;
        end record;
        S : Style;
        generic
                X : in out Boolean;
        procedure Gen;

        procedure Gen is
        begin
                S := (Table, 4);
                -- what is the value of X ??
        end;

        procedure P is new Gen (S.Four_Poster);

begin
        P;
end;
```

Would the above be allowed?

Other points

Mode out is not available.
What would that mean, anyway?

Formal objects are not static, so they can't be used in the generic in case alternatives, type ranges, floating point precisions, etc.

```
declare
    generic
        X : Integer;
    procedure Gen (Val : Integer);

    procedure Gen (Val : Integer) is
    begin
        case Val is
            when X =>
                . . .
            when others =>
                . . .
        end case;
    end Gen;

    procedure P is new Gen (X => 5);
begin
    P (Val => 8);
end;
```

You guessed it, this is illegal, too!

Parametric Confusion

When the subprograms have parameters, the syntax can be confusing.

Generic formals preceed specification but parameter list follows instantiation.

Subsequent parameters to instance also follow, but name is instance name now not generic name.

So, the text never quite matches up, as with subprograms!

```
declare
    generic
        Gen_Formal : Integer;
    procedure G (Proc_Formal : Boolean);

    procedure G (Proc_Formal : Boolean) is
    begin
        Put (Gen_Formal);
        Put (Proc_Formal);
    end G;

    procedure P is new G (Gen_Formal => 3);
begin
    P (Proc_Formal => False);
end;
```

Enough on objects... Type Parameters!

The real power of generics is revealed through the use of type (and subprogram - later) parameters

Type Parameters

```
type T is digits <>;  -- any floating point type

type T is delta <>;  -- any fixed point type

type T is range <>;  -- any integer type

type T is (<>);    -- any discrete type, which
                   -- includes integer types
```

Note allowable operations on above, such as 'First, 'Last, 'Succ, 'Pred, "*", "+", etc., are available only as appropriate (minimum assumptions)

```
generic
     type Counter is (<>);
function Gen_F (X : Counter) return Counter;

function Gen_F (X : Counter) return Counter is
begin
     return X + 1;  -- oops
end Gen_F;
```

Private Formal Parameters

type T is private;

Good news: any type except a limited type will match this formal.

Bad news: you can only declare objects, assign values to objects, and test for equality (just those operations you would expect to be able to perform on a private type).

type T is limited private;

Good news: any type including a limited type will match this formal.

Bad news: you can only declare objects and nothing else (just what you would expect to be able to do with a limited private type).

Remember, object parameters are given values by assignment, so can't have limited private object parameters (rats!).

```
generic
        File : Text_Io.File_Type;
procedure Oops;
```

Static Uses Not Allowed

```
declare

    generic
        X : Integer;
    package Static_Uses_Illegal is

        type Length is range 1 .. X;

        type Precision is digits X;

        N : constant := X;

    end Static_Uses_Illegal;

    package S is new Static_Uses_Illegal (3);

begin
    null;
end;
```

Surprise

```
declare
        subtype Small is Integer range 1..10;
        X : Integer := 27;
        generic
                S : in Small;
        procedure Gen;
        procedure Gen is
        begin
                Put ("All OK");
        end Gen;
        procedure P is new Gen (X);
begin
        P;
end;
```

-- will raise Constraint_Error at time of instantiation

```
declare
        subtype Small is Integer range 1..10;
        X : Integer := 27;
        generic
                S : in out Small;
        procedure Gen;
        procedure Gen is
        begin
                Put ("All OK");
        end Gen;
        procedure P is new Gen (X);
begin
        P;
end;
```

-- will execute OK - in spite of apparent error

Different Integer Types

Ada allows user defined Integer types:

```
type Dimension is range 0 .. 100;
```

This is really a derived type, and therefore a distinct type from type Standard.Integer.

Therefore, a utility that worked with Integers would not work with type Dimension:

```
function Is_Prime (P : Integer) return Boolean;
D : Dimension := 27;

if  Is_Prime ( D ) then  . . .     -- would not compile
```

One solution:

```
if Is_Prime ( Integer ( D ) ) then . . .  -- OK
```

Generic solution:

```
generic
        type Int_Like is range <>;
function Is_Prime ( P : Int_Like) return Boolean;

function Prime_Dimension is new
                        Is_Prime ( Int_Like => Dimension);

if Prime_Dimension ( P => D) then  . . .  --OK
```

Other Numeric Generic Parameters

Similarly, a generic could manipulate floating or fixed point numeric objects of user-defined types.

```
    function Sqrt (X : Float) return Float;
```

Would only work with values of type Float:

```
    type Precise is digits 9;
    Measurement : Precise := 2.33442_545;
begin
    Ans := Sqrt (Measurement);   -- would not compile
    Ans := Sqrt (Float (Measurement)); -- OK, but ugh
```

Better to make Sqrt generic:

```
    generic
        type Precision is digits <>;
    function Gen_Sqrt (X : Precision) return Precision;


    function Sqrt is new Gen_Sqrt (Precise);

    M := Sqrt (Measurement);
```

Note that you Don't say:

```
    function Sqrt is new Gen_Sqrt (9);
```

Fixed Point Does Not Give an Alternative

Recall that there is no general purpose fixed point type so all fixed point types (except Duration) are user-defined.

```
function Sqrt (X : No_Global_Fixed_Type)

...
```

So, fixed point routines must be generic if not in the scope of the fixed point declarations they will operate on:

```
generic
        type Fixed is delta <>;
function Gen_Fixed_Sqrt (F : Fixed) return Fixed;
```

And, instantiations would look as you would expect:

```
type Fix is delta 0.01;
function Fix_Sqrt is new Gen_Fixed_Sqrt (Fix);
```

Note, again, that the syntax of the instantiation is not:

```
function Fix_Sqrt is new Gen_Fixed_Sqrt (0.01);
```

Enumeration Types Can Also Be Passed

If a generic needs to know about an enumeration type, there is a generic formal parameter for any discrete type.

Note that integer types are also considered discrete types, so an instantiation can pass either an enumeration type or an integer type.

```
generic
        type Things is (<>);
function Number_Of_Things return Integer;

function Number_Of_Things return Integer is
begin
        return
                Things'Pos (Things'Last) -
                Things'Pos (Things'First) + 1;
end Number_Of_Things;


function Two is new
                        Number_Of_Things (Boolean);

function Look_Out is new
                        Number_Of_Things (Integer);

function Barely_Make_It is new
                        Number_Of_Things (Positive);
```

Review of Simple Parameters

To pass	Use the form
Integer	`type Int is range <>;`
Floating	`type Flt is digits <>;`
Fixed	`type Fix is delta <>;`
Discrete (integers are also discrete)	`type Enum is (<>);`

Access Type Parameters

```
generic
        type Int_Ptr is access Integer;
package Probably_Not_Too_Useful is ...
```

When one parameter depends on another:

```
package Access_Example is

        type Candy is (MM, Mars, Hershey);
        type Pointer is access Candy;

        generic
                type Blind is limited private;
                type Ptr is access Blind;
        package Lists is

                type List is limited private;
                  -- must be limited      Why?

                procedure Make (L : in out List);
                -- etc.  ...
        private
                type List is
                        record
                                Data : Blind; -- because of this
                                Link : Ptr;
                        end record;
        end Lists;

        package Candy_Chain is new Lists
                                (Blind => Candy,
                                 Ptr => Pointer
                                );
end Access_Example;
```

Structured Types

How do you pass an array to a generic?

```
generic
        type Arr is private;
        Obj : Arr;
procedure Try;



S : String (1 . . 5)  :=  "kitty";

procedure Nice_Try is new Try (String, S);



procedure Try is
begin
        Obj ( 1 ) := 'w';
end Try;
```

Sorry - no dice

To be treated as an an array, the structure of an object must be "known" to the generic:

```
generic
        type Int_Array is array
                (Integer range <>) of Integer;
procedure Sort_Array (Arr : in out Int_Array);

procedure Sort_Array (Arr : in out Int_Array) is
   Temp : Integer;
begin
  for I in Arr'First + 1 . . Arr'Last loop
        for J in Arr'First . . I - 1  loop
           if Arr (I) < Arr (J) then
                Temp := Arr (J);
                Arr (J) := Arr (I);
                Arr (I) := Temp;
           end if;
        end loop;
   end loop;
end Sort_Array;

type List is array (Integer range <>) of Integer;

procedure S is new Sort_Array (List);

L : List (1..5) := (3, 2, 4, 7, -3);

begin
    S (L);
```

Here, the component type had to be Integer, and the index range had to be an unconstrained range of Integer.

More Flexibility Possible

Above, the index type was Integer and the component type was type Integer.

Here, the index type is a range of any integer type and the component type is also any integer type.

```
generic
       type Index is range <>;
       type Component is range <>;
       type Int_Array is array (Index) of Component;
procedure Sort_Array (Arr : in out Int_Array);
procedure Sort_Array (Arr : in out Int_Array) is
   Temp : Component;
begin
  for I in Arr'First + 1 .. Arr'Last loop
       for J in Arr'First .. I - 1 loop
          if Arr (I) < Arr (J) then
               Temp := Arr (J);
               Arr (J) := Arr (I);
               Arr (I) := Temp;
          end if;
       end loop;
   end loop;
end Sort_Array;
type Short is range 1 .. 5;
type Dimension is new Integer range 0 .. 100;
type List is array (Short) of Dimension;
procedure S is new Sort_Array
                      (Short, Dimension, List);
L : List := (2, 5, 4, 6, -3);
begin
    S ( L ) ;
```

Even More Flexibility

An array must be indexed by a discrete type, but not necessarily an integer type - an enumerated type is also OK.

Also, the component type can be anything (but if assignment is needed in the generic, then it cannot be limited).

```
generic
        type Index is ( <> );
        type Component is private;
        type Int_Array is array (Index) of Component;
procedure Sort_Array (Arr : in out Int_Array);

procedure Sort_Array (Arr : in out Int_Array) is
   Temp : Component;
begin
   for I in Index'Succ (Arr'First) . . Arr'Last loop
        for J in Arr'First . . Index'Pred (I) loop
           if Arr (I) < Arr (J) then
                Temp := Arr (J);
                Arr (J) := Arr (I);
                Arr (I) := Temp;
           end if;
        end loop;
   end loop;
end Sort_Array;
type List is array (Boolean) of Float;
procedure S is new Sort_Array
                                (Boolean, Float, List);
L : List (4.5, 2.6945);
begin
S ( L );
```

Constrained vs. Unconstrainted Arrays

Note that the first example used an unconstrained type for the formal array parameter and was instantiated with an unconstrained actual array type.

The next two examples showed a constrained array type parameter and actual type.

There is NO array parameter to generics that allows either an unconstrained or constrained array type to be passed to it.

Typically, if you would like to allow either, make the generic handle unconstrained arrays, and make the user declare constrained array types based on named unconstrained types, which are the ones used for the instantiation.

```
type Short is range 1 .. 5;
type List is array (Short) of Things;
```

The above is really shorthand for

```
type Anon is new Integer;  -- or other parent type
subtype Short is Anon range 1 .. 5;

type Anon_List is array (Anon range <>) of Things;
subtype List is Anon_List (Short);
```

So, just don't take shortcuts in declaring the user array types.

No Generic Record Types

Would be nice, but the syntax and rules would have to be quite complex.

For example,

```
generic
        type First_Component is private;
        type Second_Component is private;
        type Rec is record
                Name1 : First_Component;
                Name2 : Second_Component;
        end record;
procedure Nice_Try;
```

How would you handle different sized record structures?

How would you handle initialized components?

What would you do with such general records once they were passed to the generic?

Food for thought . . .

Exceptions Raised by the Instance

Exceptions can be raised and propagated by an instance during processing.

These must be handled by the user of the instance:

```
          generic
          procedure Action;

          procedure Action is
                Error : exception;
          begin
                ...
          end Action;

          procedure Act1 is new Action;
          procedure Act2 is new Action;
          procedure Act3 is new Action;

     begin

          Act1;
          Act2;
          Act3;

     exception
          when Act1.Error =>  ... ;
          when Act2.Error =>  ... ;
          when Act3.Error =>  ... ;
```

No Exception Parameters To a Generic

Can't pass an exception to a generic to be raised:

```
          generic
                When_Trouble : exception;  -- nope
                . . .
          procedure Sort . . .
                . . .
          exception
                when others =>
                      raise When_Trouble;
          end Sort;


          My_Exception : exception;
          procedure S is new Sort (My_Exception);
    . . .
    begin
          S;
    exception
          when My_Exception =>    -- this isn't possible
                whatever. . .
    end;
```

But, There Is Something Just As Useful

Passing a subprogram to a generic is possible:

```
generic
        with procedure Call_Me_Sometime;
procedure General_Stuff;

procedure General_Stuff is
begin
        . . .
        Call_Me_Sometime;
        . . .
end General_Stuff;

procedure Wait_For_Call is
begin
        Put ("I've been called!");
end Wait_For_Call;

procedure My_Instance is new
                    General_Stuff (Wait_For_Call);

begin

    My_Instance;
                -- Wait_For_Call could now be called
                -- by the instance
```

Subprogram Parameters

Replaces the dynamic passing of subprograms such as in standard Pascal.

Enables more complete type checking, i.e., types of parameters to passed subprogram can be checked against calls to it.

Pascal problem:

```
program P;
    type
        Color = (Red, Green, Blue);
    var
        Bucket : Color;

    procedure Print (C : Color);
    begin
        case C of
            Red : write ('Red');
            Green : write ('Green');
            Blue : write ('Blue');
        end;
    end;

    procedure Proc (P : procedure);
    begin
        P (Bucket);         (* OK *)
        P (5);              (* runtime error *)
    end;

begin
    Proc (Print);
```

Ada Solution

```
declare

    type Color is (Red, Green, Blue);
    Bucket : Color := Green;

    procedure Print (C : Color) is
    begin
        Text_Io.Put (Color'Image (C));
    end Print;

    generic
        with procedure P (Val : Color);
    procedure Gen_Proc;

    procedure Gen_Proc is
    begin
        P (Bucket);         -- OK
        P (5);              -- compile time error
    end Gen_Proc;

    procedure Proc is new Gen_Proc (Print);

begin
    Proc;
end;
```

Sending the Parameter Types, Too

One of the most common uses of subprogram parameters to generics is to provide the generic with operations on user-supplied types.

Some operations are implied by the generic formal parameter:

```
type T is private;
```

allows values of this type to be assigned to variables and compared for equality

```
type T is (<>);
```

matches any discrete type
allows use of 'First, 'Last, 'Succ, 'Pred, 'Image, 'Value, 'Pos, 'Val, "<", ">", as well as above.

```
type T is range <>;
```

matches any integer type
since integer types are also discrete types, allows all of the above plus the integer operations such as "+", "-", etc.

```
type Ar is array (Index) of Component;
```

allows indexing, slicing, assigning, equating (which are special for arrays), 'Length, 'First, 'Last, etc.

When Additional Operations are Needed

For example, with array, private, and limited private types, the generic cannot perform text output of values without help from the user:

```
type Handle is access Integer;
Ptr : Handle := new Integer'(57);

function Handle_Image (L : Handle) return String is
begin
        return Integer'Image (L.all);
end Handle_Image;

generic
        type Any is limited private;
        with function String_Of (X : Any) return String;
procedure Gen_Proc (Obj : Any);

procedure Gen_Proc (Obj : Any) is
begin
        Put ("This is Gen_Proc processing . . . ");
        Put (String_Of ( Obj ) );
end Gen_Proc;

procedure Example is new Gen_Proc
                        (Handle,  Handle_Image);

procedure Interesting is new Gen_Proc
                        (Integer, Integer'Image);

begin
        Example (Ptr);
        Interesting (75);
end;
```

Default Subprogram "Values"

As with generic object and value parameters (and unlike generic type parameters - why?) generic subprogram parameters can be supplied by defaults.

For example, consider the following:

```
with Text_Io;
package Shell is

    generic
        type Any is limited private;
        with procedure Print (Val : Any) ;
    package Any_Lists is

        type Any_List is . . .

        procedure Put (L : Any_List);
        -- the body would call the generic
        -- parameter Print procedure
    end Any_Lists;

    package Char_Lists is new Any_Lists
                              (Character, Text_Io.Put);

end Shell;
```

With judicious naming of the generic subprogram parameter, a default might be possible:

```
with Text_Io;
package Shell is

    generic
        type Any is limited private;
        with procedure Put (Val : Any) is <>;
    package Any_Lists is

        type Any_List is . . .

        procedure Put (L : Any_List);
        -- the body would call the generic
        -- parameter Put procedure
    end Any_Lists;

    package Char_Lists is new Any_Lists
                              (Character);

    -- what's missing?

end Shell;
```

Remember - the resolution of the default takes place at the point of instantiation (not at the generic declaration). Otherwise, it would be trivial.

Speaking of Point of Declaration vs. Instantiation...

Also remember that global references from within a generic refer to those at the point of declaration not those at the point of instantiation. But, default references refer to matching names from the point of instantiation. Confused?

```
with Text_Io;
use Text_Io;
package Shell is

    Global : Integer := 17;

    generic
        with procedure Put (Val : Integer) is <>;
    procedure Demo;

end Shell;


package body Shell is

    procedure Demo is
    begin
        Put (Global);
    end Demo;

end Shell;
```

```
with Shell;
package Inner is
        Global : Integer := 39;

        procedure Put (I : Integer);

        procedure User is new Demo;
end Inner;


with Text_Io;
package body Inner is
        procedure Put (I : Integer) is
        begin
                Text_Io.Put
                        ("Surprise!" & Integer'Image (I));
        end Put;
end Inner;



Inner.User;
```

What gets printed?

So, generic instantiation is not simple text substitution.

Exercise

Modify the Sorting example from before so that the user can optionally change whether the sort is ascending or descending.

As before:

```
generic
        type Int_Array is array
                (Integer range <>) of Integer;
procedure Sort_Array (Arr : in out Int_Array);

procedure Sort_Array (Arr : in out Int_Array) is
   Temp : Integer;
begin
  for I in Arr'First + 1 .. Arr'Last loop
        for J in Arr'First .. I - 1  loop
           if Arr (I) < Arr (J) then
                Temp := Arr (J);
                Arr (J) := Arr (I);
                Arr (I) := Temp;
           end if;
        end loop;
   end loop;
end Sort_Array;
```

Make minimal changes to satisfy requirement.

Solution

```
generic
        type Int_Array is array
                (Integer range <>) of Integer;
        with function "<" (Left, Right : Integer)
                                        return Boolean is <>;
procedure Sort_Array (Arr : in out Int_Array);

procedure Sort_Array (Arr : in out Int_Array) is
   Temp : Integer;
begin
  for I in Arr'First + 1 .. Arr'Last loop
        for J in Arr'First .. I - 1  loop
           if Arr (I) < Arr (J) then
                Temp := Arr (J);
                Arr (J) := Arr (I);
                Arr (I) := Temp;
           end if;
        end loop;
   end loop;
end Sort_Array;
```

Instances could be declared:

```
type List is array (Integer range <>) of Integer;

procedure Ascending1 is new Sort_Array
                                (List, "<");

procedure Ascending2 is new Sort_Array (List);

procedure Descending is new Sort_Array
                                (List, ">");
```

Nesting of Generics

It can be useful to export a generic utility from a generic package. Don't clutch:

```
generic
        type Element is private;
        with function "<" (Left, Right : Element)
                                        return Boolean is <>;
package Sorted_Binary_Trees is
        type Tree is private;

        procedure Insert
                (X : Element; Into : in out Tree);

        generic
                with procedure Operate (X : Element);
        procedure Search_And_Operate (T : Tree);

end Sorted_Binary_Trees;
```

(The body is, of course, "trivially obvious to even the most casual reader". . .)

Exercise: Give an example instantiation of the above generics. (Not the body.)

A Simple Solution

```
package Int_Trees is
        new Sorted_Binary_Trees (Integer);

procedure Put_Int (X : Integer) is
begin
    Text_Io.Put ( Integer'Image (X) );
end Put_Int;

procedure Print_In_Order is new
    Int_Trees.Search_And_Operate (Put_Int);
```

Other Type Parameters

As with arrays, unconstrained types are allowed for private and limited types using the customary syntax:

```
generic
        type Furniture (Upholstered : Boolean)
                                        is private;
package P is
        Table : Furniture (False);
        Couch : Furniture (True);
end P;
```

Note that a default for the discriminant is Not allowed.

This means that an unconstrained object cannot be declared (unlike typical discriminated records)

Incidentally, a type mark must be used in a generic part, and not a subtype:

```
generic
        subtype Short is Integer range <>;
procedure Not_A_Chance;
```

More on Unconstrained Types

Peculiar situations can arise when matching a private or limited type with an actual type which is unconstrained.

If the actual type is unconstrained:

- an unconstrained array
- an unconstrained record without a default discriminant

then you can't declare an object of that type inside the generic (which includes allocators without initial values)

unless the object is a constant, meaning the initial value must have been supplied by the instantiation.

```
generic
        type T is private;
package Experiment is
        Val : T;
        type Ptr is access T;
        P : Ptr := new T;
end Experiment;


type Boo is array (Boolean range <>) of Integer;
package P is new Experiment (Boo);  -- will fail

type Rec (B : Boolean) is record
        null;
end record;
package Q is new Experiment (Rec);  -- will fail


generic
        type T is private;
        Init : T;
package Experiment is
        Val : T := Init;                    -- still a problem
        type Ptr is access T;
        P : Ptr := new T'(Init);            -- this helps
end Experiment;

type Boo is array (Boolean range <>) of Integer;
I : Boo (False . . True) := (6, 12);
package P is new Experiment (Boo, I);  -- will fail

type Rec (B : Boolean) is record
        null;
end record;
R : Rec (False) := Rec'(B => False);
package Q is new Experiment (Rec, R);  -- will fail
```

```
generic
        type T is private;
        Init : T;
package Experiment is
        Val : constant T := Init;                -- OK
        type Ptr is access T;
        P : Ptr := new T'(Init);
end Experiment;
```

```
type Boo is array (Boolean range <>) of Integer;
I : Boo (False . . True) := (6, 12);
package P is new Experiment (Boo, I);  -- OK
```

```
type Rec (B : Boolean) is record
        null;
end record;
R : Rec (False) := Rec'(B => False);
package Q is new Experiment (Rec, R);   -- OK
```

Look familiar?

```
package Counter is
        type Count is limited private;
        procedure Increment (C : in out Count);
        procedure Reset (C : out Count);
private . . .
end Counter;

package Trees is
        type Tree is limited private;
        procedure Get (T : out Tree);
        function Is_Leaf (T : Tree) return Boolean;
        procedure Split (T : in out Tree;
                         Left, Right : out Tree);
        procedure Return (T : in out Tree);
private . . .
end Trees;

with Trees;
package Piles is
        type Pile is limited private;
        function Empty (P : Pile) return Boolean;
        procedure Put (T : in out Trees.Tree;
                       On : in out Pile);
        procedure Initialize (P : in out Pile);
        procedure Get (T : out Trees.Tree;
                       From : in out Pile);
private . . .
end Piles;

with Trees, Piles, Counter;
procedure Count_Leaves is . . .
```

Generalization

```
generic
        type Object is limited private;
package General_Piles is
        type Pile is limited private;
        function Empty (P : Pile) return Boolean;
        procedure Put (T : in out Object;
                                On : in out Pile);
        procedure Initialize (P : in out Pile);
        procedure Get (T : out Object;
                                From : in out Pile);
private . . .
end Piles;
-- package is the same except for substitution
-- of Object for Trees.Tree


with Trees, General_Piles, Counter;
procedure Count_Leaves is . . .
        package Tree_Piles is
                        new General_Piles (Trees.Tree);
        . . .
-- can be the same otherwise
```

Note that this generalization was made easy due to the lack of assumptions that the original components made about each other's types.

Clue: private and limited private types assist in future generalizations of your program components.

What if the types aren't private?

Generalizations are still possible, but require more complicated generic parts.

```
package Export_Array is
        type Global_Array is array (1. .10) of Integer;
. . .

with Export_Array;
package Needs_To_See_Global_Array is
        procedure Sort
                (Ar : in out Export_Array.Global_Array);
. . .
```

To generalize the above:

```
generic
        type GA is array (1..10) of Integer;
package Needs_To_See_Global_Array is
        procedure Sort (Ar : in out GA);
. . .
```

Or better would be:

```
generic
        type Index_Range is range <>;
        type GA is array (Index_Range) of Integer;
package Needs_To_See . . .
```

But would need to ensure that the body of the package did not depend on literals unique to the original array type (i.e., that the range went from 1 to 10).

Simple Generic

Given a single state-machine implementation of stacks, the customary way to introduce many stacks is to turn it into an abstract data type:

Simple stack package:

```
package Stack is
        procedure Push (I : Integer);
        procedure Pop (I : out Integer);
        function Empty return Boolean;
        function Full return Boolean;
end Stack;
```

Conventional way to convert to many stacks:

```
package Stacks is
        type Stack is private;
        procedure Push (I : Integer; On : in out Stack);
        procedure Pop
                        (I : out Integer; From : in out Stack);
        function Empty (S : Stack) return Boolean;
        function Full (S : Stack) return Boolean;
private . . .
end Stacks;
```

User code:

```
      S : Stacks.Stack;
      I : Integer;
  begin
      Push (25, S);
      Pop (I, S);
```

Many Stacks, "Generically"

Review the original single stack:

```
package Stack is
        procedure Push (I : Integer);
        procedure Pop (I : out Integer);
        function Empty return Boolean;
        function Full return Boolean;
end Stack;
```

Illustration of generic method (not necessarily recommended, just for example):

```
generic
package Stack is
        procedure Push (I : Integer);
        procedure Pop (I : out Integer);
        function Empty return Boolean;
        function Full return Boolean;
end Stack;
```

<u>No</u> change to the body in this conversion! (Unlike the body of the private type example.)

User code:

```
    package S1 is new Stack;
    package S2 is new Stack;
    I : Integer;
begin
    S1.Push (25);
    S1.Pop (I);
```

Generic Implementations

What happens when a generic is elaborated?

What happens when an instantiation is elaborated?

It depends . . .

Suppose an initialization block appears at the end of a generic package body:

```
with Text_Io;
package body Stack is
        . . .
begin
        Text_Io.Put ("Stack instance elaborated");
end Stack;
```

Then, each of the following will cause the above Put statement to execute:

```
package S1 is new Stack;
package S2 is new Stack;
```

In the case of packages (not generics) there would only be one logical package and only one elaboration initialization would occur.

This emphasizes the fact that there are as many logical packages (or subprograms) as there are instantiations of a generic package (or subprogram).

Logical or Physical?

Debate over whether an implementation should actually create physical copies of a generic for each instance or somehow "code share" among all the instances.

Code sharing is more the way a procedure or function behaves (re-entrant).

Physical expansion (cody copying) is more the way a macro expansion behaves.

There are advantages and disadvantages of each:

Physical Expansion, Pro:

Object code executes faster because all the work is done at compile time and no context switching is needed among the instances of the same generic code.

Implementation is simpler.

Physical Expansion, Con:

Space requirements for object code can become a real problem if there a lot of instances.

Recompilation of a generic spec is always required even if just the body changes. (Why?)

Code Sharing, Pro:

Significant savings in object code size.

Generic bodies can be changed without recompiling the specs (and therefore the instantiations).

Code Sharing, Con:

Execution can be slower due to run time instantiations.

Implementation is more difficult.

So, which is it? There _is_ a "best" answer:

For a development compiler, on a host machine, where maintenance, modification, and recompilation is likely and turnaround time is more important that saving a few milliseconds at run time, you want a _code sharing_ compiler.

For a target compiler, in a time-critical application, where execution efficiency is more important that recompilation efficiency, you want a _code copying_ compiler.

It's 11:00 . . . Do you know what your compiler is doing?

(Do you know what the different vendors offer?)

More Retrofitting - Make the following general:

```
package Project is
        subtype Line is String (1..80);
        subtype Word is String (1..80);
        type Break_Chars is (' ', '-', '.', ',');
end Project;

with Project;  use Project;
procedure Next_Word (From : in out Line; Into : out Word) is
begin
        Into := (others => ' ');
        for C in 1 .. 80 loop
                -- find first non-Break_Chars letter in From
        end loop;
        for W in C .. 80 loop
                -- copy contiguous non-Break_Chars to Into
        end loop;
        for R in W+1 .. 80 loop
                -- left justify remaining letters in From
                -- and set rest to a Blank
        end loop;
end Next_Word;

with Next_Word;
with Project;  use Project;
with Text_Io;
procedure Main is
        Input_Line : Line;
        Length : Natural;
        A_Word : Word;
begin     ... -- initializations, file openings
   while not Text_Io.End_Of_File (In_File) loop
        Input_Line := (others => ' ');
        Get_Line (In_File, Input_Line, Length);
        loop
           Next_Word (From => Input_Line, Into => A_Word);
           exit when A_Word = (others => ' ');
           Put_Line (A_Word);
        end loop;
   end loop;
end Main;
```

```
package Project is
        subtype Line is String (1..80);
        subtype Word is String (1..80);
        type Break_Chars is (' ', '-', '.', ',');
end Project;

generic
        type Line is array (Positive range <>) of Character;
        type Word is array (Positive range <>) of Character;
        Break_Chars : String;
package Next_Word_Package is
        procedure Next_Word
                        (From : in out Line; Into : out Word);
end Next_Word_Package;

package body Next_Word_Package is
        procedure Next_Word
                        (From : in out Line; Into : out Word) is
begin
        Into := (others => Break_Chars (Break_Chars'First));

        . . .


with Next_Word;
with Project;  use Project;
with Text_Io;
procedure Main is
        Input_Line : Line;
        Length : Natural;
        A_Word : Word;
        package Words is new
                ...
begin     ... -- initializations, file openings
   while not Text_Io.End_Of_File (In_File) loop
        Input_Line := (others => ' ');
        Get_Line (In_File, Input_Line, Length);
        loop
           Next_Word (From => Input_Line, Into => A_Word);
           exit when A_Word = (others => ' ');
           Put_Line (A_Word);
        end loop;
   end loop;
end Main;
```

Unwrapping Ada® Packages

LCDR Melinda Moran
Computer Science Department
U. S. Naval Academy
Annapolis, MD 21401
(301) 267-2797
AV 281-2797
LINDY@USNA

Ada Program Structure

- 4 Basic Program Units:
  - Packages
  - Subprograms
  - Tasks
  - Generic Units

Packages, a Powerful Tool for Software Engineering:

- ☑ **Abstraction**
  - ☐ both data and process abstraction supported
  - ☐ layers of abstraction supported
  - ☐ facilitate managing complexity by allowing division of problem into layers of abstraction with 7 +/- 2 components each
- ☑ **Information Hiding**
  - ☐ irrelevant information hidden
  - ☐ only information relevent to each level of abstraction is visible and accessible at that level
- ☑ **Modularity**
  - ☐ facilitate creation of libraries of software modules which can be reused to implement many systems
  - ☐ facilitate easily modified systems where packages can easily be added and subtracted
- ☑ **Localization**
  - ☐ facilitate creation of very cohesive packages which can be less tightly coupled
- ☐ **Uniformity**
- ☐ **Completeness**
- ☑ **Confirmability**
  - ☐ communication only through visible interface minimizes debugging problems by minimizing "ripple" effects
  - ☐ clear definition of interfaces simplifies testing problems

PACKAGES

Definition: collection of computational resources, which may *encapsulate* data types, data objects, subprograms, tasks and even other packages.

Purpose: to express and *enforce* user's logical abstractions within the language.

Applications/Common Usages:

- Encapsulate related data types, constants or objects.
- Encapsulate related program units.
- Embody an Abstract Data Type.
- Embody an Abstract-state Machine.
- Encapsulate tasks.*

[Info taken from Software Engineering with Ada by Grady Booch with exception of *]

Structure of a Package

- Composed of 2 parts
  - Specification
    - defines the packages interface with client modules-- the types and services if offers
    - defines the portion of the package "visible" to other modules
    - must be compiled before program units which use it
    - may contain a "private" portion
  - Body
    - contains implementation details of "how" the package fulfills its contract with the client modules
    - facilitates "information hiding" -- hides irrelevant informaton from client modules
    - protects data structures and operations it encapsulates from inadvertent or malicious tampering by client module
    - may be separately compiled at a later time than specification
    - may be replaced with different implementation without recompilation "ripples" to other modules as long as specification is unchanged
    - may not be present if specification only contains types or object declarations
    - may contain a section of initialization statements and an exception handler

```
package TERMINAL_PKG is

   procedure ClearScreen;
   procedure SetCursorAt(Column, Row: in integer);
   procedure CursorUp;
   procedure CursorDown;
   procedure CursorRight;
   procedure CursorLeft;
   procedure Home;

end TERMINAL_PKG;



with TEXT_IO; use TEXT_IO;
package body TERMINAL_PKG is

   ESC : constant character := character'val(27);

   procedure Home is
      begin
         PUT(ESC);
         PUT("H");
      end;
--
   procedure ClearScreen is
      begin
         Home;
         PUT(ESC);
         PUT("J");
   end ClearScreen;
--
   procedure SetCursorAt(column, row: in integer) is
      begin
         PUT(ESC);
         PUT("Y");
         PUT(character'val(row+32));
         PUT(character'val(column+32));
      end SetCursorAt;
--
   procedure CursorUp is
      begin
         PUT(ESC);
         PUT("A");
      end;
--
   procedure CursorDown is
      begin
         PUT(ESC);
         PUT("B");
      end;
--
   procedure CursorRight is
      begin
         PUT(ESC);
         PUT("C");
      end;
--
   procedure CursorLeft is
      begin
         PUT(ESC);
         PUT("D");
      end;
--

end TERMINAL_PKG;
```

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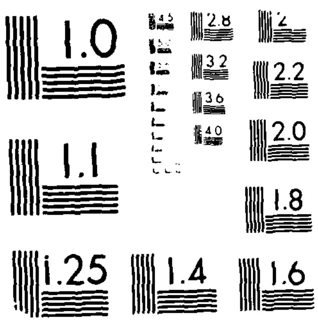


MICROCOPY RESOLUTION TEST CHART

```
-- Unit Name:  Basic_IO
-- Author:     LCDR MORAN
-- Date:       4 AUG 1987
-- Function:   Provides user ability to do input and output of
--             character, string, integer, and floating point
--             data types.

package Basic_IO is

   procedure New_Line;
   -- advances cursor to next line on the screen

   procedure Get(Item : out character);
   -- reads a single character from the keyboard

   procedure Get_Line(Item : out character);
   -- reads a single character and carriage return from the keyboard

   procedure Put(Item : in character);
   -- outputs a single character to the screen

   procedure Put_Line(Item : in character);
   -- outputs a single character to the screen and advances the cursor
   -- to the next line on the screen

   procedure Get(Item : out string);
   -- reads a string of characters from the keyboard

   procedure Get_Line(Item : out string);
   -- reads a string of characters and a carriage return from the keyboard

   procedure Put(Item : in string);
   -- outputs a string of characters to the screen

   procedure Put_Line(Item : in string);
   -- outputs a string of characters to the screen and advances the cursor
   -- to the next line on the screen

   procedure Get(Item : out integer);
   -- reads an integer fromm the keyboard

   procedure Get_Line(Item : out integer);
   -- reads an integer and a carriage return from the keyboard

   procedure Put(Item : in integer);
   -- outputs an integer to the screen

   procedure Put_Line(Item : in integer);
   -- outputs an integer to the screen and advances the cursor to the
   -- next line on the screen

   procedure Get(Item : out float);
   -- reads a floating point value from the keyboard

   procedure Get_Line(Item : out float);
   -- reads a floating point value and a carriage return from the keyboard

   procedure Put(Item : in float);
   -- outputs a floating point value to the screen

   procedure Put_Line(Item : in float);
   -- outputs a floating point value to the screen and advances the cursor
   -- to the next line on the screen

end Basic_IO;
```

```
with Text_IO;
package body Basic_IO is

   package Int_IO is new Text_IO.Integer_IO(integer);
   package Float_Point_IO is new Text_IO.Float_IO(float);


   procedure New_Line is
      begin
         Text_IO.New_Line;
      end;

   procedure Get_Line is
      Info : string(1..80);
      Count : natural;
      begin
         Text_IO.Get_Line(Info,Count);
      end;

   procedure Get(Item : out character) is
      begin
         Text_IO.Get(Item);
      end;

   procedure Get_Line(Item : out character) is
      begin
         Text_IO.Get(Item);
         Get_Line;
      end;

   procedure Put(Item : in character) is
      begin
         Text_IO.Put(Item);
      end;

   procedure Put_Line(Item : in character) is
      begin
         Text_IO.Put(Item);
         New_Line;
      end;

   procedure Get(Item : out string) is
      begin
         Text_IO.Get(Item);
      end;

   procedure Get_Line(Item : out string) is
      begin
         Text_IO.Get(Item);
         Get_Line;
      end;

   procedure Put(Item : in string) is
      begin
         Text_IO.Put(Item);
      end;

   procedure Put_Line(Item : in string) is
      begin
         Text_IO.Put(Item);

         New_Line;
      end;

   procedure Get(Item : out integer) is
      begin
         Int_IO.Get(Item);
      end;

   procedure Get_Line(Item : out integer) is
      begin
         Int_IO.Get(Item);
         Get_Line;
      end;

   procedure Put(Item : in integer) is
      begin
         Int_IO.Put(Item);
      end;

   procedure Put_Line(Item : in integer) is
      begin
         Int_IO.Put(Item);
         New_Line;
      end;

   procedure Get(Item : out float) is
      begin
         Float_Point_IO.Get(Item);
      end;

   procedure Get_Line(Item : out float) is
      begin
         Float_Point_IO.Get(Item);
         Get_Line;
      end;

   procedure Put(Item : in float) is
      begin
         Float_Point_IO.Put(Item);
      end;

   procedure Put_Line(Item : in float) is
      begin
         Float_Point_IO.Put(Item);
         New_Line;
      end;

end Basic_IO;
```

Overloading

```
package COMPLEX is
   type COMPLEX_NUMBER is record
                    REAL_PART       : FLOAT;
                    IMAGINARY_PART : FLOAT;
                  end record;
   function "+" (A,B : in COMPLEX_NUMBER) return COMPLEX_NUMBER;
   function "-" (A,B : in COMPLEX_NUMBER) return COMPLEX_NUMBER;
end COMPLEX;

package body COMPLEX is
   function "+" (A,B : in COMPLEX_NUMBER) return COMPLEX_NUMBER is
       RESULT : COMPLEX_NUMBER;
   begin
     RESULT.REAL_PART := A.REAL_PART + B.REAL_PART;
     RESULT.IMAGINARY_PART := A.IMAGINARY_PART + B.IMAGINARY_PART;
     return RESULT;
   end;

   function "-" (A,B : in COMPLEX_NUMBER) return COMPLEX_NUMBER is
       RESULT : COMPLEX_NUMBER;
   begin
     RESULT.REAL_PART := A.REAL_PART - B.REAL_PART;
     RESULT.IMAGINARY_PART := A.IMAGINARY_PART - B.IMAGINARY_PART;
     return RESULT;
   end;
end COMPLEX;
```

Overloading continued

```
package FRACTIONS is
    type FRACTION is record
                        NUMERATOR       : NATURAL;
                        DENOMINATOR     : NATURAL;
                      end record;
    function "+" (A,B  : in FRACTION) return FRACTION;
    function "-" (A,B  : in FRACTION) return FRACTION;
end FRACTIONS;

package body FRACTIONS  is
    function "+" (A,B : in FRACTION) return FRACTION is
        RESULT : FRACTION;
    begin
      RESULT.NUMERATOR := (A.NUMERATOR * B.DENOMINATOR) +
                          (B.NUMERATOR * A.DENOMINATOR);
      RESULT.DENOMINATOR := A.DENOMINATOR + B.DENOMINATOR;
      return RESULT;
    end;

    function "-" (A,B : in FRACTION) return FRACTION is
       RESULT : FRACTION;
    begin
      RESULT.NUMERATOR := (A.NUMERATOR * B.DENOMINATOR) -
                          (B.NUMERATOR * A.DENOMINATOR);
      RESULT.DENOMINATOR := A.DENOMINATOR + B.DENOMINATOR;
      return RESULT;
    end;
end FRACTIONS;
```

Overloading continued

```
with COMPLEX, FRACTIONS;
use COMPLEX, FRACTIONS;
procedure ARITHMETIC is
  X : FRACTION := (3,4);
  Y : FRACTION := (5,6);
  FRACTION_RESULT : FRACTION := (1,1);

  A : COMPLEX_NUMBER := (5,7);
  B : COMPLEX_NUMBER := (8,9);
  COMPLEX_RESULT : COMPLEX_NUMBER := (0,0);

begin
  FRACTION_RESULT := X + Y;
  COMPLEX_RESULT :=  A + B;

  FRACTION_RESULT := X - Y;
  COMPLEX_RESULT := A - B;
end;
```

Packages with No Body

```
package CALENDAR is
  type DAY is (MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY,
               SATURDAY, SUNDAY);
  type MONTH is (JANUARY, FEBRUARY, MARCH, APRIL, MAY, JUNE,
                 JULY, AUGUST, SEPTEMBER, OCTOBER, NOVEMBER,
                 DECEMBER);
  type YEAR is range 0 .. INTEGER'LAST;
end CALENDAR;
```

```
package METRIC_EARTH_CONSTANTS is
  EQUATORIAL_RADIUS      : constant := 6378.145;     --km
  GRAVITATION_CONSTANT   : constant := 3.986012e5;   --km**3/sec**2
  SPEED_UNIT             : constant := 7.90536828;   --km/sec
  TIME_UNIT              : constant := 806.8118744;  -- sec
end METRIC_EARTH_CONSTANTS;
```

[METRIC_EARTH_CONSTANTS package taken from Software Engineering with Ada by Grady Booch]

```
with TYPES;
use TYPES;
package GIGI_GRAPHICS_PKG is

-----------------------------------------------------------------
   procedure SETSCREENSCALE(left,right,top,bottom: in integer);
   procedure CLEARSCREEN;
   procedure SETSCREENCOLOR(color : in colortype);
   procedure SETREVERSEVIDEO;
   procedure SETNORMALVIDEO;
   procedure FREEZESCREEN(ticks : in integer);
   procedure MOVECURSORABS(xcoord,ycoord : in integer);
   procedure SETCURSORAT(xcoord,ycoord : in integer);
   procedure MOVECURSORREL(xincr,yincr : in integer);
   procedure QUERYCURSORPOS(xcoord,ycoord : out integer);
   procedure SAVELASTMOVELOC;
   procedure RESTORELASTMOVELOC;
   procedure PUTDOT;
   procedure DRAWLINETO(xcoord,ycoord : in integer);
   procedure DRAWPOLYLINE(coordarray : in coordarraytype;
                      num_of_coord_pairs : in integer);
   procedure DRAWCIRCLE(xcoord,ycoord,radius : in integer);
   procedure SETSHADINGREFLINE(y_value: in integer);
   procedure SETSHADINGCHAR(shading_char : in character);
   procedure SETSHADINGON;
   procedure SETSHADINGOFF;
   procedure SAVELASTDRAWLOC;
   procedure RESTORELASTDRAWLOC;
   procedure SETWRITINGCOLOR(color : in colortype);
   procedure SETWRITINGMODE(mode : in modetype);
   procedure SETTEXTSIZE(size : in integer);
   procedure SETTEXTPATH(angle : in integer);
   procedure SETTEXTHEIGHT(height : in integer);
   procedure SETITALICSANGLE(angle : in integer);
   procedure SETBLINKOFF;
   procedure SETBLINKON;
   procedure SAVETEXTATTRIBUTES;
   procedure RESTORETEXTATTRIBUTES;
   procedure OUTPUT(integer_val : in integer);
   procedure OUTPUT(text_val : in string);
   procedure OUTPUT(char_val : in character);
end GIGI_GRAPHICS_PKG;
-----------------------------------------------------------------
```

```
with TEXT_HANDLER;
use TEXT_HANDLER;
package body GIGI_GRAPHICS_PKG is

   -- current screen scale bounds
   CLEFT : integer := 0;          -- current left x-axis value
   CRIGHT : integer := 767;       -- current right x-axis value
   CTOP : integer := 0;           -- current top y-axis value
   CBOTTOM : integer := 479;      -- current bottom y-axis value

   -current cursor position
   CP_X : integer := 0;           -- current position, x-value
   CP_Y: integer := 0;            -- current position, y-value

---------------------------------------------------------------
task SEMAPHORE is
   entry SEIZE;
   entry RELEASE;
end SEMAPHORE;

task body SEMAPHORE is
   IN_USE : boolean := false;
begin
   loop
      select
         when not IN_USE =>
            accept SEIZE do
               IN_USE := true;
            end SEIZE;
      or
         when IN_USE =>
            accept RELEASE do
               IN_USE := false;
            end RELEASE;
      end select;
   end loop;
end SEMAPHORE;
---------------------------------------------------------------
```

```
function INBOUNDS(xcoord,ycoord : in integer) return boolean is
   xvalid, yvalid : boolean;
begin
   -- check if xcoord between left and right screen scale bounds
   if ((xcoord >= cleft) and (xcoord <= cright)) or
      ((xcoord <= cleft) and (xcoord >= cright)) then
      xvalid := true;
   else
      xvalid := false;
   end if;

   -- check if ycoord between top and bottom screen scale bounds
   if ((ycoord >= ctop) and (ycoord <= cbottom)) or
      ((ycoord <= ctop) and (ycoord >= cbottom)) then
      yvalid := true;
   else
      yvalid := false;
   end if;
   if (xvalid) and (yvalid) then
      return true;
   else
      return false;
   end if;
end;
-----------------------------------------------------------------
procedure CLEARSCREEN is
   T : TEXT;
begin
   T := TO_TEXT(esc) & "Pp" & "S(E)" & esc & "\";
   PUT(T);
end;
-----------------------------------------------------------------
procedure SETSCREENCOLOR(color : in colortype) is
   x : integer;
   T : text;
begin
   x := colortype'pos(color);   -- x=ordinal position of color chosen
                                -- see colortype in types package
   T := TO_TEXT(esc) & "Pp" & "S(I" & integer'image(x) & ")"
        & esc & "\";
   PUT(T);
end;
-----------------------------------------------------------------
procedure SETREVERSEVIDEO is
   T : TEXT;
begin
   T := TO_TEXT(esc) & "Pp" & "S(N1)" & esc & "\";
   PUT(T);
end;
-----------------------------------------------------------------
```

Specification Structure

- 2 Parts
  - Visible portion
    - extends from beginning of package specification up to word "private"
    - Client modules can "see" and use the types, objects, subprograms in this section
    - Resources in this part of the spec are said to be "exported"

- Private portion
  - Part of the specification that follows the word "private"
  - Types declared in this portion of the spec can be seen "textually" but their structural components are not accessible to/corruptible by the client
  - Declaration of types as private facilitates use of abstraction where client operates with logical properties of the type and cannot access the details of its physical implementation
  - Private types can only be declared in the visible part of a package; their implementation is in the private part of the package
  - 2 categories of private type
    - private types - can use operations declared in visible part of pkg spec, assignment operator, eq. and inequality op.
    - limited private types - same as for private types except assignment, eq. and inequality operations unavailable

```
package Fractions is

   type Fraction is
     record
        Numerator: Integer := 0;
        Denominator: positive := 1;
     end record;


   function MakeFraction(N, D: Integer) return Fraction;
        -- "create"

   function Numer(x: Fraction)           return Integer;
   function Denom(x: Fraction)           return Integer;
        -- decomposition

   function "+"(x, y: Fraction)          return Fraction;
   function "-"(x, y: Fraction)          return Fraction;
   function "*"(x, y: Fraction)          return Fraction;
   function "/"(x, y: Fraction)          return Fraction;
        -- arithmetic

   function Equal(x, y: Fraction)        return boolean;
   function "<"(x, y: Fraction)          return boolean;
   function ">="(x, y: Fraction)         return boolean;
        -- comparison

   function Reduce(x: Fraction)          return Fraction;
   function FractionToInt(x: Fraction)   return Integer;
   function IntToFraction(I: Integer)    return Fraction;
        -- miscellaneous

end Fractions;
```

Figure 1-7 Package specification for Fractions

```
package Fractions is

   type Fraction is private;

   function MakeFraction(N, D: Integer)  return Fraction;
        -- "create"

   function Numer(x: Fraction)           return Integer;
   function Denom(x: Fraction)           return Integer;
        -- decomposition

   function "+"(x, y: Fraction)          return Fraction;
   function "-"(x, y: Fraction)          return Fraction;
   function "*"(x, y: Fraction)          return Fraction;
   function "/"(x, y: Fraction)          return Fraction;
        -- arithmetic

   function Equal(x, y: Fraction)        return boolean;
   function "<"(x, y: Fraction)          return boolean;
   function ">="(x, y: Fraction)         return boolean;
        -- comparison

   function Reduce(x: Fraction)          return Fraction;
   function FractionToInt(x: Fraction)   return Integer;
   function IntToFraction(I: Integer)    return Fraction;
        -- miscellaneous

private
   type Fraction is
      record
         Numerator: Integer := 0;
         Denominator: positive := 1;
      end record;

end Fractions;
```

Figure 1-9 Package specification using a private type

```
package body Fractions is

   -- code for function body MakeFraction

   function Numer(x: Fraction) return Integer is
      begin
         return x.Numerator;
      end Numer;

   -- code for function body Denom
   -- code for function body "+"

   function "-"(x, y: Fraction) return Fraction is
       N: Integer;
       D: positive;
      begin
         N := Numer(x)*Denom(y) - Numer(y)*Denom(x);
         D := Denom(x)*Denom(y);
         return Reduce(MakeFraction(N,D));
      end "-";

   -- code for function body "*"
   -- code for function body "/"
   -- code for function body Reduce

   function Equal(x, y: Fraction) return boolean is
      begin
         return Numer(x)*Denom(y)=Numer(y)*Denom(x);
      end Equal;

   -- code for function body "<"
   -- code for function body ">="

   function FractToInt(x: Fraction) return Integer is
      begin
         return Numer(x)/Denom(x);
      end FractToInt;

   function IntToFract(I: Integer) return Fraction is
      begin
         return(I, 1);
      end IntToFract;


end Fractions;
```

Figure 1-8 Partial package body for Fractions

[Taken from Data Structures with Ada by Michael B Feldman]

```
package KEY_MANAGER is
  type KEY is private;
  procedure GET_KEY(K : out KEY);
  function "<" (X,Y : KEY) return BOOLEAN;
private
  type KEY is new INTEGER range 0 .. INTEGER'LAST;
end KEY_MANAGER;

package body KEY_MANAGER is
  NEXT_KEY : KEY := 1; -- own variable - exists between
                       -- procedure calls
procedure GET_KEY(K : out KEY) is
begin
  K := NEXT_KEY;
  NEXT_KEY := NEXT_KEY + 1;
end GET_KEY;

function "<"(X,Y : KEY) return BOOLEAN is
begin
  return INTEGER(X)<INTEGER(Y);
end "<";
end KEY_MANAGER;
```

[Taken from Programming with Ada by Peter Wegner]

```
package B_R is

    type NUMBERS is range 0 .. 99;

    procedure TAKE (A_NUMBER : out NUMBERS);
    procedure SERVE (NUMBER : in NUMBERS);
    function  NOW_SERVING return NUMBERS;

end B_R;

package body B_R is

    SERV_A_MATIC : NUMBERS := 1;

    procedure TAKE (A_NUMBER : out NUMBERS) is
    begin
        A_NUMBER     := SERV_A_MATIC;
        SERV_A_MATIC := SERV_A_MATIC + 1;
    end TAKE;

    procedure SERVE (NUMBER : in NUMBERS) is separate;

    function  NOW_SERVING return NUMBERS is separate;

end B_R;
```

```
with B_R;
use  B_R;
procedure ICE_CREAM is

    YOUR_NUMBER : NUMBERS;

begin

    TAKE (YOUR_NUMBER);
    loop

        if NOW_SERVING = YOUR_NUMBER then
            SERVE (YOUR_NUMBER);
            exit;
        end if;

    end loop;

end ICE_CREAM;
```

```
with B_R;
use  B_R;
procedure ICE_CREAM is

    YOUR_NUMBER : NUMBERS;

begin

    TAKE (YOUR_NUMBER);
    loop

        if NOW_SERVING = YOUR_NUMBER then
            SERVE (YOUR_NUMBER);
            exit;
        else
            YOUR_NUMBER := YOUR_NUMBER - 1;
        end if;

    end loop;

end ICE_CREAM;
```

[Taken from Keesler AFB, ATC Course Student Handout]

```
package B_R is

    type NUMBERS is private;

    procedure TAKE (A_NUMBER : out NUMBERS);
    procedure SERVE (NUMBER : in NUMBERS);
    function  NOW_SERVING return NUMBERS;

private

    type NUMBERS is range 0 .. 99;

end B_R;


with B_R;
use  B_R;
procedure ICE_CREAM is

    YOUR_NUMBER : NUMBERS;

begin

    TAKE (YOUR_NUMBER);
    loop

        if NOW_SERVING = YOUR_NUMBER then
            SERVE (YOUR_NUMBER);
            exit;
        else
            YOUR_NUMBER := NOW_SERVING;
        end if;

    end loop;

end ICE_CREAM;
```

```
package B_R is

    type NUMBERS is limited private;

    procedure TAKE (A_NUMBER : out NUMBERS);
    procedure SERVE (NUMBER : in NUMBERS);
    function  NOW_SERVING return NUMBERS;
    function  "=" (LEFT, RIGHT : in NUMBERS)
                  return BOOLEAN;
    function  CLOSE_ENOUGH (A_NUMBER : in NUMBERS)
                  return BOOLEAN;
private

    type NUMBERS is range 0 .. 99;

end B_R;


with B_R;
use  B_R;
procedure ICE_CREAM is

    YOUR_NUMBER : NUMBERS;

    procedure GO_TO_DQ is separate;

begin

    TAKE (YOUR_NUMBER);
    if NOW_SERVING = YOUR_NUMBER then
        SERVE (YOUR_NUMBER);
    elsif CLOSE_ENOUGH (YOUR_NUMBER) then

        while NOW_SERVING /= YOUR_NUMBER loop
            null;                      -- wait your turn
        end loop;
        SERVE (YOUR_NUMBER);

    else
        GO_TO_DQ;
    end if;

end ICE_CREAM;
```

Implications of Using the Specification's Private Section

- Forces recompilation of specification and any client modules if the data structure used to implement a type changes.

- Can be avoided if data structure needed for a package can be internal to the body of the package but this disables client's ability to declare multiple objects of a particular type. Haberman and Perry refer to "open type" and "unique object" solutions.

- Can be avoided by making private type an "access" (pointer) type

Ada Open Type Solution

```
package QueueManager is

    qsize : constant INTEGER := 10;
    subtype qindex is INTEGER range 0 .. qsize - 1;

    type bodies is array(qindex) of FLOAT;
    type queue is record
        head   : qindex := 0;
        length : INTEGER range 0 .. qsize := 0;
        qbody  : array (qindex) of FLOAT;
    end record;

    function  FULL  (q : in queue) return BOOLEAN;
    function  EMPTY (q : in queue) return BOOLEAN;
    procedure ENQ   (q : in out queue ; r : in FLOAT);
    procedure DEQ   (q : in out queue ; r : out FLOAT);

    overflow, underflow : exception;

end QueueManager;


package body QueueManager is

    function FULL(q : in queue) return BOOLEAN is
    begin
        return q.length = qsize;
    end FULL;

    function EMPTY(q : in queue) return BOOLEAN is
    begin
        return q.length = 0;
    end EMPTY;

    procedure ENQ(q : in out queue ; r : in FLOAT) is
    begin
        if FULL(q) then raise overflow ; end if;
        q.qbody(q.head + q.length) mod qsize := r;
        q.length := q.length + 1;
    end ENQ;

    procedure DEQ(q : in out queue ; r : out FLOAT) is
    begin
        if EMPTY(q) then raise underflow ; end if;
        r := q.qbody (q.head);
        q.head := (q.head + 1) mod qsize;
        q.length := q.length - 1;
    end DEQ;

end QueueManager;
```

Ada Program for the Queue as a Unique Object

```
package RealQueue is

    function  FULL  return BOOLEAN;
    function  EMPTY return BOOLEAN;
    procedure ENQ   (r : in FLOAT);
    function  DEQ   return FLOAT;

    overflow, underflow : exception;

end RealQueue;


package body RealQueue is

    qsize : constant INTEGER := 10;
    subtype qindex is INTEGER range 0 .. qsize - 1;

    head   : qindex;
    length : INTEGER range 0 .. qsize;
    qbody  : array (qindex) of FLOAT;

    function FULL return BOOLEAN is
    begin
        return length = qsize;
    end FULL;

    function EMPTY return BOOLEAN is
    begin
        return length = 0;
    end EMPTY;

    procedure ENQ(r : in FLOAT) is
    begin
        if FULL then raise overflow ; end if;
        qbody (head + length) mod qsize := r;
        length := length + 1;
    end ENQ;

    function DEQ return FLOAT is
        r : FLOAT := qbody (head);
    begin
        if EMPTY then raise underflow ; end if;
        head := (head + 1) mod qsize;
        length := length - 1;
        return r;
    end DEQ;

begin
    head := 0;
    length := 0;
end RealQueue;
```

[from Ada for Experienced Programmers by A Nico Habermann and Dewayne E Perry]

```
package Fractions is
-- modified version of Fractions Package taken from Data
--   Structures with Ada by M. B. Feldman

   type Fraction is private;

   function MakeFraction(N, D : integer) return Fraction;
   procedure Put(X : in Fraction);

   function Numer(X : Fraction)                  return integer;
   function Denom(X : Fraction)                  return integer;

   function "+"(X, Y : Fraction)                 return Fraction;
   function "-"(X, Y : Fraction)                 return Fraction;
   function "*"(X, Y : Fraction)                 return Fraction;
   function "/"(X, Y : Fraction)                 return Fraction;
   function Reciprocal(X : Fraction)             return Fraction;

   function Equal(X, Y : Fraction)               return boolean;
   function "<"(X, Y : Fraction)                 return boolean;
   function ">="(X, Y : Fraction)                return boolean;

   function Reduce(X : Fraction)                 return Fraction;
   function ToDecimal(X : Fraction)              return float;
   function IntegerToFraction(I : integer)       return Fraction;
   function FractionToInteger(X : Fraction)      return integer;

   ZeroDenominatorError : exception;

private
   type Fraction_Node;
   type Fraction is access Fraction_Node;

end Fractions;
```

```
with Text_IO;
package body Fractions is

   type Fraction_Node is array(1..2) of integer;

   package Int_IO is new Text_IO.Integer_IO(integer);

   function MakeFraction(N, D : integer) return Fraction is
      F : Fraction;
      begin
         if D /= 0 then
            F := new Fraction_Node;
            -- for fractions < 0, the numerator carries the negative sign
            if D < 0 then
               F(1) := -N;
               F(2) := -D;
            else
               F(1) := N;
               F(2) := D;
            end if;
            return F;
         else
            raise ZeroDenominatorError;
         end if;
      end MakeFraction;


   function Numer(X : Fraction)                  return integer is
      begin
         return X(1);
      end Numer;

   function Denom(X : Fraction)                  return integer is
      begin
         return X(2);
      end Denom;

   procedure Put(X : in Fraction) is
      begin
         Int_IO.Put(Numer(X),1);
         Text_IO.Put("/");
         Int_IO.Put(Denom(X),1);
         Text_IO.Put("hi there");
      end Put;

   function GCD(X, Y : integer)                  return integer is
      begin
         if Y = 0 then
            return X;
         else
            return GCD(Y,X mod Y);
         end if;
      end GCD;

   procedure Swap(X, Y : in out integer);

   procedure Swap(X, Y : in out integer) is
      Temp : integer;
      begin
```

```
package body Fractions is

   type Fraction_Node is
      record
         Numerator : integer     := 0;
         Denominator : integer   := 1;
      end record;

   package Int_IO is new Text_IO.Integer_IO(integer);

   function MakeFraction(N, D : integer) return Fraction is
      F : Fraction;
      begin
         if D /= 0 then
            F := new Fraction_Node;
            -- for fractions < 0, the numerator carries the negative sign
            if D < 0 then
               F.Numerator := -N;
               F.Denominator := -D;
            else
               F.Numerator := N;
               F.Denominator := D;
            end if;
            return F;
         else
            raise ZeroDenominatorError;
         end if;
      end MakeFraction;


   function Numer(X : Fraction)              return integer is
      begin
         return X.Numerator;
      end Numer;

   function Denom(X : Fraction)              return integer is
      begin
         return X.Denominator;
      end Denom;

   procedure Put(X : in Fraction) is
      begin
         Int_IO.Put(Numer(X),1);
         Text_IO.Put("/");
         Int_IO.Put(Denom(X),1);
      end Put;

   function GCD(X, Y : integer)              return integer is
      begin
         if Y = 0 then
            return X;
         else
            return GCD(Y,X mod Y);
         end if;
      end GCD;

   procedure Swap(X, Y : in out integer);

   procedure Swap(X, Y : in out integer) is

       Temp : integer;
       begin
          Temp := X;
          X := Y;
          Y := Temp;
       end Swap;

    function Reduce(X : Fraction)            return Fraction is
       N, D : integer;
       begin
          N := Abs(Numer(X));
          D := Abs(Denom(X));
          if N > D then
             Swap(N,D);
          end if;
          return MakeFraction(Numer(X)/GCD(N,D), Denom(X)/GCD(N,D));
       end Reduce;

    function Reciprocal(X : Fraction)        return Fraction is
       begin
```

```
function "+"(X, Y : Fraction)              return Fraction is
   begin
      return Reduce( MakeFraction(Numer(X)*Denom(Y)+Numer(Y)*Denom(X),
                          Denom(X)*Denom(Y)) );
   end "+";

function "-"(X, Y : Fraction)              return Fraction is
   begin
      return Reduce( MakeFraction(Numer(X)*Denom(Y)-Numer(Y)*Denom(X),
                          Denom(X)*Denom(Y)) );
   end "-";

function "*"(X, Y : Fraction)              return Fraction is
   begin
      return Reduce( MakeFraction(Numer(X)*Numer(Y),Denom(X)*Denom(Y)) );
   end "*";

function "/"(X, Y : Fraction)              return Fraction is
   begin
      return Reduce( (X*Reciprocal(Y)) );
   end "/";

function Equal(X, Y : Fraction)            return boolean is
   begin
      return Numer(X)*Denom(Y) = Numer(Y)*Denom(X);
   end Equal;

function "<"(X, Y : Fraction)              return boolean is
   begin
      return Numer(X)*Denom(Y) < Numer(Y)*Denom(X);
   end "<";

function ">="(X, Y : Fraction)             return boolean is
   begin
      return Numer(X)*Denom(Y) >= Numer(Y)*Denom(X);
   end ">=";

function ToDecimal(X : Fraction)           return float is
   begin
      return float(Numer(X)) / float(Denom(X));
   end ToDecimal;

function IntegerToFraction(X : integer)    return Fraction is
   begin
      return MakeFraction(X,1);
   end IntegerToFraction;

function FractionToInteger(X : Fraction)   return integer is
   begin
      return Numer(X) / Denom(X);
   end FractionToInteger;

end Fractions;
```

```
package MANAGER is
  type PASSWORD is private;
  NULL_PASSWORD : constant PASSWORD;
  function GET return PASSWORD;
  function IS_VALID(P : in PASSWORD) return BOOLEAN;
private
  type NODE;
  type PASSWORD is access NODE;
end MANAGER;

package body MANAGER is
  type NODE is range 0 .. 7000;
.
.
.
end MANAGER;
```

[Taken from Software Engineering with Ada by Grady Booch]

- Reason private types must be included in private part of the specification rather than put in the body of a package is that compiler needs to be able to determine how much storage to allocate for instances of private types declared by client modules.

- "Inclusion of private data types in the package specification implies that a change in representation of the private data type will require recompilation of the program unit which contains the package specification, thus violating the principle that package specifications are recompiled only when there are specification changes which affect the user. This appears to be a very heavy price to pay for the simplification in compiling and loading that is achieved by including private declarations in the specification part." [Taken from Programming with Ada by Peter Wegner]

Using a Package

- via textual inclusion in the client module
  - package has NOT been separately compiled
  - package is visible in client from the point it is first declared
  - spec and body do not have to be textually contiguous in client but spec must come first

- via context specification using the "with" clause
  - package has been separately compiled and is made visible via the "with" clause
  - this method supports ideas of modularity and localization better than textual inclusion method
  - must prefix references to items with the package's name and a period
  - necessitates prefix form of notation for use of an overloaded operator such as "+" or "-" , etc.
  - can use "renames" clause to allow use of operators in infix form
  - can use "USE" clause to gain direct visibility to items in the package
  - use of "USE" clase can create ambiguity and pollute the name space
- Both methods import ALL elements of the visible part of a package -- no selective importation such as in Modula 2 -- argues for carefully segmenting packages to achieve same effect

```
procedure COMPLEX_COMPUTATIONS is
  procedure ONE,
  procedure TWO;
  package COMPLEX is . . .
  procedure ONE is . . .
  procedure TWO is . . .
  package body COMPLEX is . . .

  X, Y, Z : COMPLEX.COMPLEX_NUMBER;
begin
  Z := COMPLEX."+"(X,Y);
end;
***********************************************************************
with COMPLEX;
procedure COMPLEX_COMPUTATIONS is
  procedure ONE;
  procedure TWO;
  procedure ONE is . . .
  procedure TWO is . . .

  X, Y, Z : COMPLEX.COMPLEX_NUMBER;
 begin
  Z := COMPLEX."+"(X,Y);
end;
***********************************************************************
with COMPLEX; use COMPLEX;
procedure COMPLEX_COMPUTATIONS is
  procedure ONE,
  procedure TWO;
  procedure ONE is . . .
  procedure TWO is . . .

  X, Y, Z : COMPLEX_NUMBER;
begin
  Z := X + Y;
end;
```

Example of a PACKAGE

```
package GOLF_INFO is

   type GOLF_CLUB    is (DRIVER, IRON, PUTTER, WEDGE, MASHIE);
   type GOLF_SCORE   is range 1 .. 200;
   type HOLE_NUMBER  is range 1 .. 18;
   type HANDICAP     is range 0 .. 36;
   type SCORE_DATA   is array (HOLE_NUMBER) of GOLF_SCORE;
   PAR_FOR_COURSE :  constant GOLF_SCORE := 72;
   PAR_VALUES :  constant SCORE_DATA :=
                (1 => 5,  2 => 3,  3 => 4,  4 => 4,  5 => 3,  6 => 4,
                 7 => 5,  8 => 4,  9 => 4,  10=> 3,  11=> 4, 12=> 4,
                 13=> 4,  14=> 5,  15=> 3, 16=> 4, 17=> 4, 18=>5);

   procedure COMPUTE_TOTAL_SCORE(SCORES: in SCORE_DATA;
                                 TOTAL: out GOLF_SCORE);

end GOLF_INFO;

package body GOLF_INFO is

   procedure COMPUTE_TOTAL_SCORE(SCORES: in SCORE_DATA;
                                 TOTAL: out GOLF_SCORE) is
     begin
       TOTAL := 0;
       for HOLE in HOLE_NUMBER loop
         TOTAL := TOTAL + SCORES(HOLE);
       end loop;
     end;

end GOLF_INFO;
```

[Taken from *Ada: An Introduction* by Henry Ledgard]

Using the PACKAGE

```
with GOLF_INFO, TEXT_IO;
use GOLF_INFO, TEXT_IO;
procedure KEEP_SCORE is

   MY_SCORES    : SCORE_DATA;
   TOTAL_SCORE  : GOLF_SCORE;

begin

   PUT("Let's have the scores for each hole.");
   for HOLE in HOLE_NUMBER loop
     NEW_LINE;
     PUT(HOLE);  PUT("  ");
     GET(MY_SCORES(HOLE));
   end loop;

   COMPUTE_TOTAL_SCORE(MY_SCORES, TOTAL_SCORE);
   NEW_LINE;
   PUT("Your total is ");  PUT(TOTAL_SCORE);

   NEW_LINE;
   if TOTAL_SCORE < PAR_FOR_COURSE then
     PUT(PAR_FOR_COURSE - TOTAL_SCORE);  PUT(" Under Par");
   elsif TOTAL_SCORE = PAR_FOR_COURSE then
     PUT("An Even Par");
   else
     PUT(TOTAL_SCORE - PAR_FOR_COURSE);  PUT(" Over Par");
   end if;

end KEEP_SCORE;
```

[Taken from *Ada: An Introduction* by Henry Ledgard]

```
procedure OUTER is
  package HEIGHT is
    ID : INTEGER;
    VALUE : FLOAT;
  end HEIGHT;

  package WEIGHT is
    ID : INTEGER;
    VALUE : FLOAT,
  end WEIGHT;

  procedure INNER is
    use HEIGHT, WEIGHT,
  begin
    HEIGHT.VALUE := 65.3,
    WEIGHT.VALUE := HEIGHT.VALUE;
     VALUE := 63.5;     -- unqualified name causes ambiguity
  end INNER;

begin
  VALUE := 63.5;        -- illegal because outside scope of USE
                        --   statement so name must be qualified
end;
```

[Example taken from Programming with Ada by Peter Wegner]

PROGRAM 3.8 Modula-2 Version of Program 3.7

```
(* This definition module is a separate compiland and is
   compiled before the program ReverseName is compiled. *)

DEFINITION MODULE Stacks;
(* $SEG:=8; *)
(* This is a compiler directive required by the particular operating system being
   used. It assigns a segment number of a definition module. In general, this is
   not required. *)

   EXPORT QUALIFIED
        (* type *) Stack,
        (* proc *) Empty,
        (* proc *) Pop,
        (* proc *) Push,
        (* proc *) Initialize,
        (* proc *) Remove;

   TYPE Stack;  (* Representational details hidden  *)

   PROCEDURE Empty(S: Stack) : BOOLEAN;
   (* Returns true if stack is empty. *)

   PROCEDURE Pop(VAR S: Stack) : CHAR;
   (* Strips top element off stack. *)

   PROCEDURE Push(VAR S: Stack; X: CHAR);
   (* Adds element to top of stack. *)

   PROCEDURE Initialize(VAR S: Stack);
   (* Sets stack to empty. *)

   PROCEDURE Remove(VAR S: Stack);
   (* Removes stack from memory. *)

END Stacks.
-----------------------------------
```

[illegible]

PROGRAM 3.8 Modula-2 Version of Program 3.7

```
(• This definition module is a separate compiland and is
   compiled before the program ReverseName is compiled. •)

DEFINITION MODULE Stacks;
(• $SEG:=8; •)
(• This is a compiler directive required by the particular operating system being
   used. It assigns a segment number of a definition module. In general, this is
   not required. •)

  EXPORT QUALIFIED
      (• type •) Stack,
      (• proc •) Empty,
      (• proc •) Pop,
      (• proc •) Push,
      (• proc •) Initialize,
      (• proc •) Remove;

  TYPE Stack;  (• Representational details hidden  •)

  PROCEDURE Empty(S: Stack) : BOOLEAN;
  (• Returns true if stack is empty. •)

  PROCEDURE Pop(VAR S: Stack) : CHAR;
  (• Strips top element off stack. •)

  PROCEDURE Push(VAR S: Stack; X: CHAR);
  (• Adds element to top of stack. •)

  PROCEDURE Initialize(VAR S: Stack);
  (• Sets stack to empty. •)

  PROCEDURE Remove(VAR S: Stack);
  (• Removes stack from memory. •)

END Stacks.
-----------------------------------
```

Implementation Details of Module Stacks

```
IMPLEMENTATION MODULE Stacks;

    FROM Terminal IMPORT WriteString, WriteLn;

    FROM Storage  IMPORT ALLOCATE, DEALLOCATE;

    CONST STACKSIZE = 80;

    TYPE Objects = ARRAY [1..STACKSIZE] OF CHAR;

         Stack = POINTER TO RECORD
                              ITEM: Objects;
                              TOP : CARDINAL
                            END;

    PROCEDURE Empty(S: Stack) : BOOLEAN;
    BEGIN
        IF S↑.TOP = 0 THEN
            RETURN TRUE
        ELSE
            RETURN FALSE
        END
    END Empty;

PROCEDURE Pop(VAR S: Stack) : CHAR;
(• Strips top element off stack. •)
BEGIN
    IF Empty(S) THEN
        WriteString("Stack underflow.");
        WriteLn;
        HALT;
    ELSE
        DEC(S↑.TOP);
        RETURN S↑.ITEM[S↑.TOP+1];
    END
END Pop;
```

[Taken from Software Engineering with Modula-2 and Ada by R. Wiener and R. Sincovec]

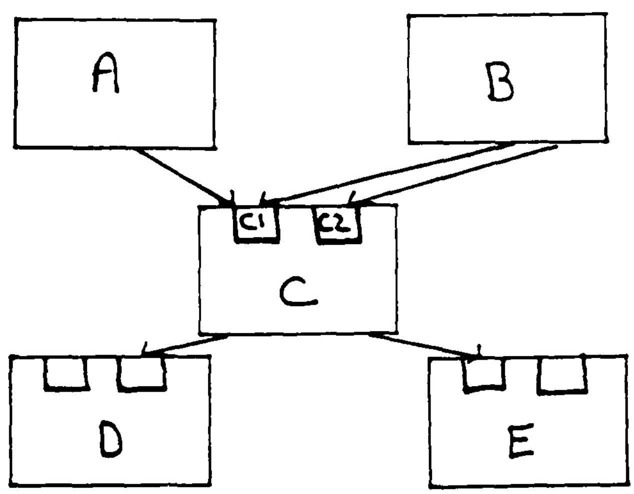
```
MODULE ReverseName;  (* This is the program. *)

(* In Modula-2, all reserved words must be given in uppercase. *)

    FROM Stacks IMPORT Empty, Pop, Initialize, Remove, Stack;

    FROM InOut IMPORT WriteString, WriteLn, Write, Read, EOL;

    PROCEDURE Find Middle (VAR S : Stack) : CHAR;
    (* We use an algorithm different from that in Program 3.7. *)

    VAR LocalStack: Stack;
        ch        : CHAR;

    BEGIN
        Initialize(LocalStack);
        REPEAT
            ch:=Pop(S);
            Push(LocalStack,ch);
        UNTIL ch= '.';
        ch:=Pop(S);
        Push(LocalStack,ch);
        (* Now we restore the stack S to its original form. *)
        WHILE NOT Empty(LocalStack) DO
            Push(S,Pop(LocalStack));
        END;
        RETURN ch
    END FindMiddle;

    VAR Name        : ARRAY[1..40] OF CHAR;
        A           : Stack;

        •
        •
        •
```

[Taken from Software Engineering with Modula-2 and Ada
by R. Wiener and R. Sincovec]

Limitations on Structure Specifications in Ada

- No support for declaration of structure graph interconnections at specification level

- Can include this information with comments as an alternative




```
package C is
  required(D,E);
  is required by (A,B);
  procedure C1( ... );
  procedure C2( ... );
end package C;
```

[Taken from System Design with Ada by R.J.A. Buhr]

Package Applications

- Encapsulate related data types, constants or objects.
  - only objects and types exported, no pgm units
  - package body may or may not be present
  - facilitates consistency by factoring out common elements used by may modules

- Encapsulate related program units.
  - only program units exported, no objects and types

- Embody an Abstract Data Type (ADT)
  - objects, types, and program units exported
  - state information not maintained in body of the pkg
  - supports abstraction and information hiding

- Embody an Abstract-state machine.
  - objects, types, and program units exported
  - state information maintained in body of pkg

- Encapsulate tasks.*
  - often used purely to enclose task(s) because they cannot be separately compiled

[Info from Software Engineering with Ada by Grady Booch with exception of *]

```
package TRIG_PKG is

function FACTORIAL(n: in integer) return float;
-- returns n! as a floating point value

function SIMPLIFY(angle_in_degrees : in integer) return integer;
-- returns an equivalent angle (in degrees) for ANGLE_IN_DEGREES
-- which is positive and between 0 and 360

function RADIANS(degrees : in integer) return float;
-- returns radian value for DEGREES

function SIN(angle_in_degrees : in integer) return float;
-- returns the sine of ANGLE_IN_DEGREES

function COS(angle_in_degrees : in integer) return float;
-- returns the cosine of ANGLE_IN_DEGREES

end TRIG_PKG;
-----------------------------------------------------------

package body TRIG_PKG is

   FACT : array(0..15) of float :=
          (1.0,
           1.0,
           2.0,
           6.0,
           24.0,
           120.0,
           720.0,
           5040.0,
           40320.0,
           362880.0,
           3628800.0,
           39916800.0,
           479001600.0,
           6227020800.0,
           87178291200.0,
           1307674368000.0);

function FACTORIAL(n: in integer) return float is
   x : float := 1.0;
begin
   if n < 0 then
      -- if n is NEGATIVE return ZERO to indicate ERROR
      return 0.0;
   elsif ((n >= 0) and (n <=15)) then
      return FACT(n);
   elsif n > 15 then
      for i in 1..n loop
         x := x * float(i);
      end loop;
      return x;
   end if;
end;
```

```
function SIMPLIFY(angle_in_degrees : in integer) return integer is
   angle : integer;
begin
   angle := angle_in_degrees rem 360;
   if angle < 0 then
      angle := 360 + angle;
   end if;
   return angle;
end;

function RADIANS(degrees : in integer) return float is
   pi : float := 3.14159265;
begin
   return ((pi/float(180)) * float(degrees));
end;

function SIN(angle_in_degrees : in integer) return float is
   sum : float := 0.0;
   angle : integer;
   temp_angle : integer;
begin
   temp_angle:= SIMPLIFY(angle_in_degrees);
   if temp_angle >= 180 then
      -- First and second quadrant angles used for computation
      --     because computation is more accurate
      angle := temp_angle - 180;
   else
      angle := temp_angle;
   end if;
   for i in 0..7 loop
    sum := sum + (   ( float(((-1)**i)) * (RADIANS(angle)**(2*i+1)) )
                    / ( FACT(2*i+1) )   );
   end loop;

   -- Account for use of only first and second quadrant angles
   --     in computation
   if temp_angle > 180 then
      return (-sum);
   else
      return sum;
   end if;
end;

function COS(angle_in_degrees : in integer) return float is
   sum : float := 0.0;
   angle : integer;
   temp_angle : integer;
begin
   temp_angle := SIMPLIFY(angle_in_degrees);
   if temp_angle >= 180 then
      -- First and second quadrant angles used for computation
      --     because computation is more accurate
      angle := temp_angle -180;
   else
      angle := temp_angle;
   end if;
   for i in 0..7 loop
    sum := sum + (   ( float(((-1)**i)) * (RADIANS(angle)**(2*i)) )
                    / ( FACT(2*i) )   );
   end loop;

   -- Account for use of only first and second quadrant angles
   --     in computation
   if temp_angle >= 180 then
      return (-sum);
   else
      return sum;
   end if;
end;

end TRIG_PKG;
```

```
with TRIG_PKG, GIGI_GRAPHICS_PKG, TYPES;
use TRIG_PKG, GIGI_GRAPHICS_PKG, TYPES;
package TURTLES is

   subtype ANGLE is integer range 0..360;
   type TURTLE is private;

-------------------------------------------------------------------
                    -- TURTLE CONTROLS --
-------------------------------------------------------------------
  -- PEN CONTROLS
     procedure UP(myturtle : in out TURTLE);
     procedure DOWN(myturtle : in out TURTLE);
     function  PEN_IS_DOWN(myturtle : in turtle) return boolean;
     procedure NEW_PEN(myturtle : in out TURTLE; colour : in COLORTYPE);

  -- MOVEMENT CONTROLS
     procedure NORTH(myturtle : in out TURTLE);
     procedure SOUTH(myturtle : in out TURTLE);
     procedure EAST(myturtle : in out TURTLE);
     procedure WEST(myturtle : in out TURTLE);
     procedure MOVE(myturtle : in out TURTLE; n : in integer);
     procedure TURN(myturtle : in out TURTLE; a : in ANGLE);
     procedure TURN_TO(myturtle : in out TURTLE; a : in ANGLE);
-------------------------------------------------------------------


-------------------------------------------------------------------
private
   type POSITION is (pen_up,pen_down);

   type PEN is record
                 pen_position : POSITION;
                 pen_colour : COLORTYPE;
              end record;

   subtype XCOORD is integer range 0..768;
   subtype YCOORD is integer range 0..479;

   type POINT is record
                   x : XCOORD;
                   y : YCOORD;
                end record;

   type TURTLE is record
                    pen_status : PEN := (pen_down,white);
                    heading : ANGLE := 0;
                    location : POINT := (350,250);
                 end record;
-------------------------------------------------------------------
  d TURTLES;
```

```
------------------------------------------------------------------------
package body TURTLES is

-   --------------------------------------------------------------------
                    -- TURTLE PEN CONTROLS --
------------------------------------------------------------------------
procedure SET_PEN_COLOUR(myturtle : in out TURTLE; colour : in COLORTYPE);
procedure SET_PEN_COLOUR(myturtle : in out TURTLE; colour : in COLORTYPE) is
begin
   myturtle.pen_status.pen_colour := colour;
end;


procedure NEW_PEN(myturtle : in out TURTLE; colour : in COLORTYPE) is
begin
   SET_PEN_COLOUR(myturtle,colour);
end;


function PEN_IS_DOWN(myturtle : in TURTLE) return boolean is
begin
   if myturtle.pen_status.pen_position = pen_down then
      return true;
   else
      return false;
   end if;
end;


  .edure UP(myturtle : in out TURTLE) is
begin
   myturtle.pen_status.pen_position := pen_up;
end;


procedure DOWN(myturtle : in out TURTLE) is
begin
   myturtle.pen_status.pen_position := pen_down;
end;
```

```
---------------------------------------------------------------
            -- DRAWING and UN-DRAWING the TURTLE --
---------------------------------------------------------------
rocedure TRANSFORM(myturtle : in TURTLE; x : in integer; y : in integer;
                   new_x : out XCOORD; new_y : out YCOORD;
                   theta : in ANGLE);
rocedure TRANSFORM(myturtle : in TURTLE; x : in integer; y : in integer;
                   new_x : out XCOORD; new_y : out YCOORD;
                   theta : in ANGLE) is
egin
  new_x :=  myturtle.location.x +
            integer(float(x)*COS(theta) - float(y)*SIN(theta));
  new_y :=  myturtle.location.y  +
            integer(float(x)*SIN(theta) + float(y)*COS(theta));
nd;


rocedure DRAW_TURTLE(myturtle : in TURTLE);
rocedure DRAW_TURTLE(myturtle : in TURTLE) is
  x,y : integer;
egin
  SETWRITINGMODE(replace);
  SETWRITINGCOLOR(myturtle.pen_status.pen_colour);
  SETCURSORAT(myturtle.location.x,myturtle.location.y);
  TRANSFORM(myturtle,0,-18,x,y,myturtle.heading);
  DRAWLINETO(x,y);
  TRANSFORM(myturtle,24,0,x,y,
            myturtle.heading);
   AWLINETO(x,y);
  RANSFORM(myturtle,0,18,x,y,
            myturtle.heading);
  DRAWLINETO(x,y);
  TRANSFORM(myturtle,0,0,x,y,
            myturtle.heading);
  DRAWLINETO(x,y);
  SETCURSORAT(myturtle.location.x,myturtle.location.y);
nd;


  ..dure UNDRAW_TURTLE(myturtle : in TURTLE);
  ..dure UNDRAW_TURTLE(myturtle : in TURTLE) is
  x,  . integer;

  SETWRITINGMODE(erase);
  SETWRITINGCOLOR(dark);
  SETCURSORAT(myturtle.location.x,myturtle.location.y);
  TRANSFORM(myturtle,0,-18,x,y,myturtle.heading);
  DRAWLINETO(x,y);
  TRANSFORM(myturtle,24,0,x,y,
            myturtle.heading);
  DRAWLINETO(x,y);
  TRANSFORM(myturtle,0,18,x,y,
            myturtle.heading);
  DRAWLINETO(x,y);
  TRANSFORM(myturtle,0,0,x,y,
            myturtle.heading);
  DRAWLINETO(x,y);
  SETCURSORAT(myturtle.location.x,myturtle.location.y);
end;
```

```
-----------------------------------------------------------------------
                    -- TURTLE MOVEMENT CONTROLS --
-----------------------------------------------------------------------
procedure MOVE(myturtle : in out TURTLE; n : in integer) is
begin
   UNDRAW_TURTLE(myturtle);
   if PEN_IS_DOWN(myturtle) then
      SETWRITINGMODE(replace);
      SETWRITINGCOLOR(myturtle.pen_status.pen_colour);
      DRAWLINETO(integer( float(n)*COS(myturtle.heading)+
                          float(myturtle.location.x) ),
                 integer( float(n)*SIN(myturtle.heading)+
                          float(myturtle.location.y) ) );
   else
      MOVECURSORABS(integer( float(n)*COS(myturtle.heading)+
                          float(myturtle.location.x) ),
                 integer( float(n)*SIN(myturtle.heading)+
                          float(myturtle.location.y) ) );
   end if;
   QUERYCURSORPOS(myturtle.location.x,myturtle.location.y);
   DRAW_TURTLE(myturtle);
end;


procedure TURN(myturtle : in out TURTLE; a : in ANGLE) is
begin
   UNDRAW_TURTLE(myturtle);
   myturtle.heading := SIMPLIFY(myturtle.heading + a);
   DRAW_TURTLE(myturtle);
end;


procedure TURN_TO(myturtle : in out TURTLE; a : in ANGLE) is
begin
   UNDRAW_TURTLE(myturtle);
   myturtle.heading := a;
   DRAW_TURTLE(myturtle);
end;


procedure NORTH(myturtle : in out TURTLE) is
begin
   TURN_TO(myturtle,90);
   MOVE(myturtle,1);
end;


procedure SOUTH(myturtle : in out TURTLE) is
begin
   TURN_TO(myturtle,270);
   MOVE(myturtle,1);
end;


procedure EAST(myturtle : in out TURTLE) is
begin
   TURN_TO(myturtle,0);
   MOVE(myturtle,1);
end;


procedure WEST(myturtle : in out TURTLE) is
begin
   TURN_TO(myturtle,180);
   MOVE(myturtle,1);
end;
-----------------------------------------------------------------------



begin
   SETSCREENSCALE(0,760,470,0);
   CLEARSCREEN;
   SETCURSORAT(0,0);
end TURTLES;
```

```
package LEXICAL_ANALYZER is
  procedure SET_START_STATE;
  procedure RECEIVE_SYMBOL(C : in CHARACTER);
  IDENTIFIER_ACCEPTED : exception;
  INVALID_CHARACTER   : exception;
  MACHINE_HALTED      : exception;
  NUMBER_ACCEPTED     : exception;
end LEXICAL_ANALYZER;
```

[Taken from Software Engineering with Ada by Grady Booch]

```
package body LEXICAL_ANALYZER is
  type STATE is (START, BUILD_IDENTIFIER, BUILD_NUMBER, STOP);
  PRESENT_STATE : STATE := START;
  subtype ALPHA is CHARACTER range 'A' .. 'Z';
  subtype DIGIT is CHARACTER range '0' .. '9';
  procedure SET_START_STATE is
  begin
    PRESENT_STATE := START;
  end SET_START_STATE;
 procedure RECEIVE_SYMBOL(C : in CHARACTER) is
 begin
   case PRESENT_STATE is
     when START            => if (C in ALPHA) then
                                PRESENT_STATE := BUILD_IDENTIFI
                              elsif (C in DIGIT) then
                                PRESENT_STATE := BUILD_NUMBER;
                              else
                                raise INVALID_CHARACTER;
                              end if;
     when BUILD_IDENTIFIER => if (C in ALPHA) or (C in DIGIT) t
                                null;
                              else
                                PRESENT_STATE := STOP;
                                raise IDENTIFIER_ACCEPTED;
                              end if;
     when BUILD_NUMBER     => if (C not in DIGIT) then
                                PRESENT_STATE := STOP;
                                raise NUMBER_ACCEPTED;
                              end if;
     when STOP             => raise MACHINE_HALTED;
   end case;
  end RECEIVE_SYMBOL;
end LEXICAL_ANALYZER;
```

```
package Terminal_Driver_Package is

   task Terminal_Driver is
      entry Read_Character(C : out Character);
      entry Write_Character(C : in Character);
      entry Reset;
      entry ShutDown;
   end Terminal_Driver;

end Terminal_Driver_Package;

with Queue_Package, Low_Level_IO, System;
use Low_Level_IO;

package body Terminal_Driver_Package is

   task body Terminal_Driver is

      -- Group all of the machine dependent constants together

      Console_Input_Vector : constant System.Address := 8#60#;
      Console_Output_Vector : constant System.Address := 8#64#;
      Enable_Interrupts : Integer := 8#100#;
      Write_Time_Out : constant Duration := 0.5;
      Number_Of_Lines: constant := 2;
      LineLength: constant := 132;

      task type Device_Reader is
         entry Interrupt;
         entry StartUpDone;
         for Interrupt use at Console_Input_Vector;
      end Device_Reader;

      task type Device_Writer is
         entry Interrupt;
         entry StartUpDone;
         for Interrupt use at Console_Output_Vector;
      end Device_Writer;

      package Char_Queue_Package is new Queue_Package(Character);
      use Char_Queue_Package;

      type DriverStateBlock is
         record
            InputCharBuffer, OutputCharBuffer :
               Blocking_Queue(Number_Of_Lines*LineLength);
            CurReader : Device_Reader;
            CurWriter : Device_Writer;
         end record;

      type RefToBlock is access DriverStateBlock;
      CurState: RefToBlock;

      task body Device_Reader is
         TempInput : Character;
      begin
         accept StartUpDone;
         Send_Control(Console_Keyboard_Control, Enable_Interrupts);
         loop
            accept Interrupt do
               Receive_Control(Console_Keyboard_Data, TempInput);
            end Interrupt;
            Append(CurState.InputCharBuffer, TempInput);
         end loop;
      end Device_Reader;
```

```
task body Device_Writer is
   TempOutput : Character;
begin
   accept StartUpDone;
   Send_Control(Console_Printer_Control, Enable_Interrupts);
   accept Interrupt; -- spurious interrupt caused by Send_Control
   loop
      Remove(CurState.OutputCharBuffer, TempOutput);
      Send_Control(Console_Printer_Data, TempOutput);
      select
         accept Interrupt;
      or
         delay Write_Time_Out;
      end select;
   end loop;
end Device_Writer;

procedure ShutDownOld is
begin
   abort CurState.CurReader;
   abort CurState.CurWriter;
   Destroy_Queue(CurState.InputCharBuffer);
   Destroy_Queue(CurState.OutputCharBuffer);
end ShutDownOld;

procedure StartUp is
begin
   CurState := new DriverStateBlock;
   Init_Queue(CurState.InputCharBuffer);
   Init_Queue(CurState.OutputCharBuffer);
   CurState.CurReader.StartUpDone;
   CurState.CurWriter.StartUpDone;
end StartUp;
begin
   StartUp;

Console_Operations:
   loop
      select
         accept Read_Character(C : out Character) do
            Remove(CurState.InputCharBuffer, C);
         end Read_Character;
      or
         accept Write_Character(C : in Character) do
            Append(CurState.OutputCharBuffer, C);
         end Write_Character;
      or
         accept Reset do
            ShutDownOld;
            StartUp;
         end Reset;
      or
         accept ShutDown;
         ShutDownOld;
         exit Console_Operations;
      or
         terminate;
      end select;
   end loop Console_Operations;
exception
   when others =>
      ShutDownOld;

end Terminal_Driver;

end Terminal_Driver_Package;
```


[Taken from Studies in Ada Style]

Teaching Packages

- ☐ Start at the PACKAGE level and then introduce the syntax by example -- NOT at the syntax level and then intro packages -- good way to produce Fortran programs written in Ada

- ☐ Give students preconstructed packages and have them build defined products with them

- ☐ Have students play "client" package and package developer

- ☐ Have students develop a larger scale system with packages that must interface

- ☐ Have students build a system which has a heirarchical structure of packages

- ☐ Have students do a package and replace its implementation and observe results

- Give students package with "open" data structure in the spec and have them corrupt its integrity and then challenge them to do the same thing with a package with the data structure in the private part of the spec

  - Data structures course very easy vehicle for introducing packages under topic of abstraction

  - Digital design course offers opportunity to intro packages to encapsulate abstract-state machines and tasks

David A. Cook
INSTRUCTOR COMPUTER SCIENCE
U.S. AIR FORCE ACADEMY, CO 80840

472-3590
AV 259-3590
DFCS

HOME 472-6935
QTRS 4206F
USAFA, CO 80840

Ada* Tasking
Abstraction of Process

Captain David A. Cook
U.S. Air Force Academy

*Ada is a registered trademark of the U.S. Government, Ada Joint Program Office

ADA TASKING

- OVERVIEW

  DEFINE ADA TASKING

  DEFINE SYNCHRONIZATION MECHANISM

  EXAMPLES

Ada Tasking

Task Definition

- A program unit for concurrent execution
- Never a Library Unit
- Master is a ...
  - Library Package
  - Subprogram
  - Block Statement
  - Other Task

Ada Tasking

Synchronization Mechanisms

- Global Variables
- Rendezvous

Main Program in a task

Caller Requests Service

1. Immediate Request
2. Wait for a While
3. Wait Forever

CALLEE PROVIDES SERVICE

1. IMMEDIATE RESPONSE

2. WAIT FOR A WHILE

3. WAIT FOREVER

SERVICE IS REQUESTED WITH AN ENTRY CALL STATEMENT

SERVICE IS PROVIDED WITH AN ACCEPT STATEMENT

ADA TASKING

SELECT STATEMENTS PROVIDE ABILITY TO PROGRAM THE DIFFERENT REQUEST AND PROVIDE MODES

GUARDS ARE "IF STATEMENTS" FOR PROVIDING SERVICE

TERMINATION IS AN ALTERNATIVE IF A SERVICE IS NO LONGER NEEDED

TASK MASTERS

EACH TASK MUST DEPEND ON A MASTER

A MASTER CAN BE A TASK, A CURRENTLY EXECUTING BLOCK STATEMENT, A CURRENTLY EXECUTING SUBPROGRAM, OR A LIBRARY PACKAGE.

PACKAGES DECLARED INSIDE ANOTHER PROGRAM UNIT CANNOT BE MASTERS.

THE MASTER OF A TASK IS DETERMINED BY THE CREATION OF THE TASK OBJECT.

A BLOCK, TASK, OR SUBPROGRAM CANNOT BE LEFT UNTIL ALL OF ITS DEPENDENTS ARE TERMINATED.

FOR THE MAIN PROGRAM, TERMINATION DOES NOT DEPEND ON TASK WHOSE MASTER IS A LIBRARY PACKAGE.

ACTUALLY, THE 1815A DOES NOT DEFINE IF TASKS THAT DEPEND ON LIBRARY PACKAGES ARE REQUIRED TO TERMINATE!!

WHEN DOES A TASK START?

TASKS ARE ACTIVATED AFTER THE ELABORATION OF THE DECLARATIVE PART.

EFFECTIVELY, ACTIVATION IS AFTER THE DECLARATIVE PART, AND IMMEDIATELY AFTER THE 'BEGIN' STATEMENT, BUT BEFORE ANY OTHER STATEMENT.

THE PURPOSE OF THIS IS TO ALLOW THE EXCEPTION HANDLER TO SERVICE TASK EXCEPTION.

```
Task type T1 is ....
Obj : T1;

begin
    declare
    New_Obj:T1;

    begin
       null;
    end;
...
...
end;
```

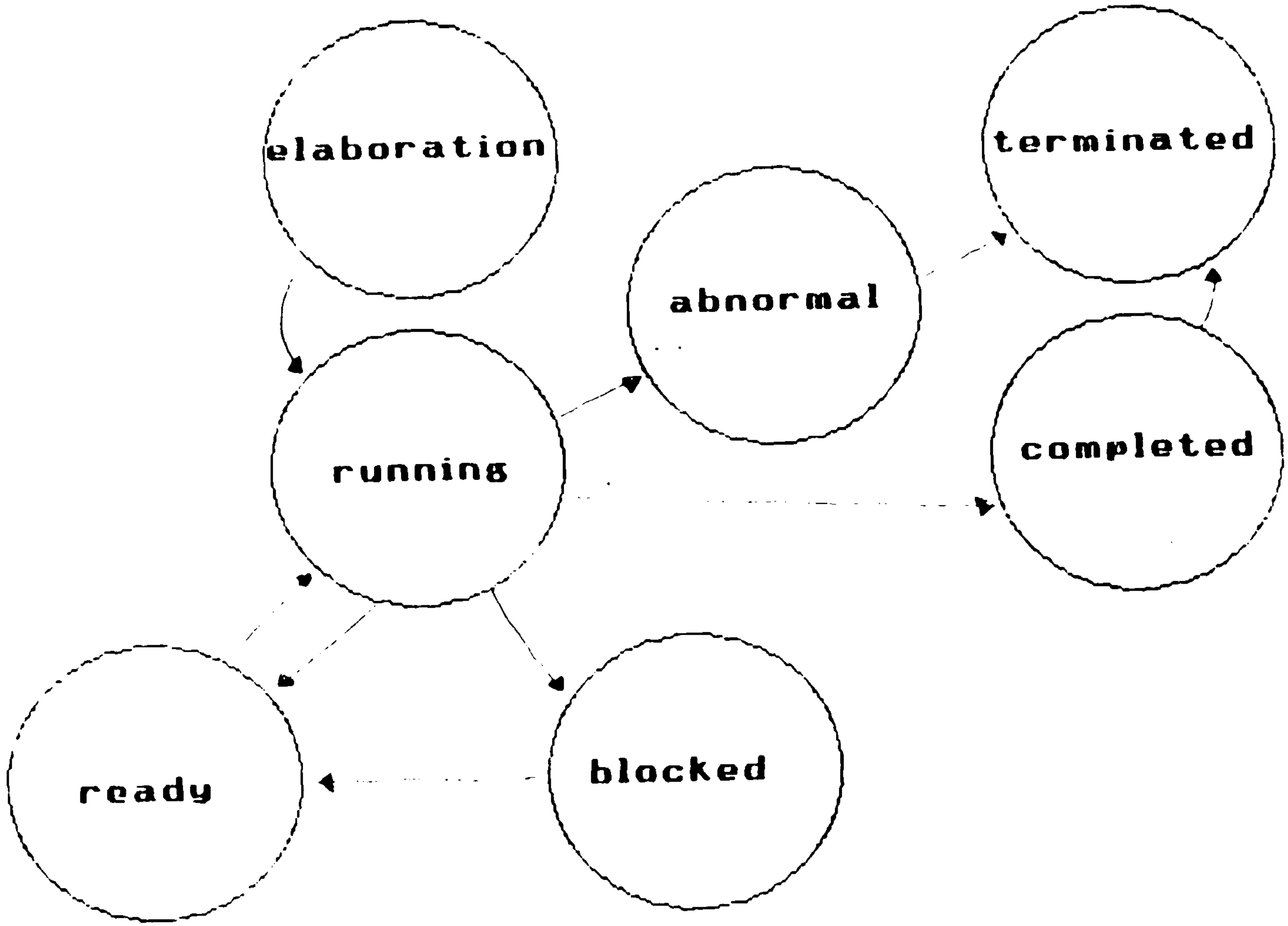
TASKS OBJECTS ACCESSED BY ALLOCATORS DO THINGS A LITTLE BIT DIFFERENTLY

NORMALLY, THE SCOPE OF A TASK OBJECT DETERMINES ITS MASTER

FOR AN ACCESS TYPE, THE MASTER IS DETERMINED BY THE ACCESS TYPE DEFINITION

ACTIVATION FOR ACCESSED TASKS OCCURS IMMEDIATELY UPON THE ASSIGNMENT OF A VALUE TO THE ACCESS OBJECT

```
Task Type T1 is...
Obj : T1;
Type T1_Ptr is access T1;
Ptr_Obj : T1_Ptr := new T1;

begin
    declare
    New_Ptr_Obj:T1_Ptr:=new T1;

    begin
      null;
    end;

...
...
end;
```


elaboration
running
abnormal
terminated
completed
ready
blocked

ELABORATION	-	DECLARATIVE PART
RUNNING	-	TASK HAS PROCESSOR
READY	-	TASK IS AVAILABLE FOR PROCESSOR, AND HAS ALL RESOURCES TO RUN
BLOCKED	-	TASK IS EITHER WAITING FOR A CALL, OR WAITING FOR CALL TO BE ANSWERED
COMPLETED	-	AT END, OR EXCEPTION
TERMINATED	-	COMPLETED, AND DEPENDENT TASKS ALSO TERMINATED
ABNORMAL	-	TASK WAS ABORTED

```
task [type] [is
   {entry_declaration}
   {representation_clause}
end [task_simple_name] ]


task body task_simple_name is
   [declarative_part]
begin
   [sequence_of_statements]
[exception
   exception_handler
  {exception_handler}]
end [task_simple_name];
```

ACCEPT STATEMENT

THE ACCEPT STATEMENT ALLOWS AN UNKNOWN CALLER TO CALL AN ENTRY.

THERE CAN BE IN AND/OR OUT PARAMETERS

THE CONSTRUCT IS 'ACCEPT.....DO'

DURING THE ACCEPT, THE CALLING UNIT IS SUSPENDED. THUS, A LONG ACCEPT SLOWS DOWN THE SYSTEM.

A GOOD APPROACH IS TO USE THE ACCEPT SIMPLY TO COPY IN OR OUT DATA, AND ALLOW THE CALLER TO CONTINUE.

SIMPLEST FORM OF TASK ENTRY

ACCEPT

```
TASK T1 IS
    ENTRY ENTRY1;
END T1;
.
.
TASK BODY T1 IS
  BEGIN
    LOOP

          ACCEPT ENTRY1 DO
                <SOS>
          END ENTRY1;
       <SOS>

       END LOOP;
  END T1;
--WAIT FOREVER FOR CALL TO ENTRY1
```

```
TASK T1 IS
  ENTRY ACTION (DATA : SOME_TYPE);
END T1;

TASK BODY T1 IS

  BEGIN
    LOOP
      ACCEPT ACTION(DATA:SOME_TYPE) DO
        --SOME LONG PROCESS USING DATA
        --  OCCURS HERE
      END ACTION;
    END LOOP;
  END T1;

--NO EXITS OR GOTOS ALLOWED IN ACCEPT,
--  BUT A RETURN IS ALLOWED
```

```
TASK T1 IS
  ENTRY ACTION (DATA : SOME_TYPE);
END T1;


TASK BODY T1 IS
  LOCAL : SOME_TYPE;
  BEGIN
    LOOP
      ACCEPT ACTION(DATA:SOME_TYPE) DO
        LOCAL := DATA;
      END ACTION;
       --PUT PROCESS ON LOCAL HERE
    END LOOP;
  END T1;
--WHEN THIS CAN BE DONE, IT WILL SPEED
--UP THE SYSTEM.
```

```
TASK T1 IS
  ENTRY ACTION(DATA:A_TYPE);
  ENTRY RESULT(DATA :OUT A_TYPE);
END T1;

TASK BODY T1 IS
  LOCAL : A_TYPE;
  BEGIN
    LOOP
      ACCEPT ACTION(DATA:A_TYPE) DO
        LOCAL := DATA;
      END ACTION;
      --PROCESS ON LOCAL HERE
      ACCEPT R   T(DATA:OUT A_TYPE) DO
        DATA :
      END RES
    END LOOP;
  END T1;
```

```
TASK T1 IS
     ENTRY ENTRY1;
END T1;
.
.
TASK BODY T1 IS
  BEGIN
    LOOP

          ACCEPT ENTRY1; --'SYNC' CALL ONLY
     <SOS>

     END LOOP;
  END T1;
--WAIT FOREVER FOR CALL TO ENTRY1


--EVEN IF ENTRY1 HAS PARAMETERS ASSOCIATED WITH
--    IT, THE ACCEPT BLOCK DOES NOT HAVE TO HAVE A
--    SEQUENCE OF STATEMENTS
```

SELECT STATEMENT

USED BY THE TASK TO ALLOW OPTIONS

SIMPLEST FORM IS THE SELECTIVE WAIT (WAIT FOREVER)

```
TASK T1 IS
    ENTRY ENTRY1;
    ENTRY ENTRY2;
END T1;
.
.
.
TASK BODY T1 IS
 BEGIN
   LOOP
      SELECT
         ACCEPT ENTRY1 DO
           <SOS>
         END ENTRY1;
         <SOS>
      OR
         ACCEPT ENTRY2 DO
           <SOS>
         END ENTRY2;
         <SOS>

     --AS MANY 'OR' AND ACCEPT CLAUSES AS NEEDED

      END SELECT;
    END LOOP;
 END T1;
--WAIT FOR EITHER ENTRY1 OR ENTRY2
```

SELECTIVE WAIT WITH ELSE (DON'T WAIT AT ALL)

```
TASK T1 IS
    ENTRY ENTRY1;
END T1;
.
.
.
TASK BODY T1 IS
  BEGIN
   LOOP
    SELECT
      ACCEPT ENTRY1 DO
         <SOS>
      END ENTRY1;
      <SOS>
    ELSE
      <SOS>
    END SELECT;
   END LOOP;
  END T1;
```

IF THERE IS NOT A CALLER WAITING <u>RIGHT NOW</u>,
DO THE ELSE PART.

SELECTIVE WAIT WITH ELSE, MULTIPLE
ACCEPTS

```
TASK T1 IS
     ENTRY ENTRY1;
     ENTRY ENTRY2;
END T1;


TASK BODY T1 IS
  BEGIN
    LOOP
      SELECT
         ACCEPT ENTRY1 DO
           <SOS>
         END ENTRY1;
         <SOS>
      OR
         ACCEPT ENTRY2 DO
           ...
      -- AS MANY 'OR' AND 'ACCEPT' CLAUSES AS NEEDED

      ELSE
         <SOS>;
      END SELECT;
    END LOOP;
  END T1;
```

SELECT WITH DELAY ALTERNATIVE
(WAIT A FINITE TIME)

```
TASK BODY T1 IS
BEGIN
  LOOP
    SELECT
      ACCEPT ENTRY1 DO....
    [OR
      ACCEPT ENTRY2.....]
    OR
      DELAY 15.0; --SECONDS
      <SOS>;
    END SELECT;
  END LOOP;
END T1;
```

IF ENTRY1 CALLED WITHIN 15 SECONDS, THEN YOU ACCEPT THE CALL. OTHERWISE, AFTER 15 SECONDS YOU WILL DO SOMETHING.

'DELAY' RULES

YOU MAY HAVE SEVERAL ALTERNATIVES WITH A DELAY STATEMENT.

SINCE DELAYS CAN BE STATIC, THE SHORTEST DELAY ALTERNATIVE WILL BE SELECTED.

ZERO AND NEGATIVE DELAYS ARE LEGAL.

YOU MAY NOT HAVE AN ELSE PART WITH A DELAY, SINCE THE DELAY WOULD NEVER BE ACCEPTED.

'DELAY' RULES

YOU MAY HAVE SEVERAL ALTERNATIVES WITH A DELAY STATEMENT.

SINCE DELAYS CAN BE STATIC, THE SHORTEST DELAY ALTERNATIVE WILL BE SELECTED.

ZERO AND NEGATIVE DELAYS ARE LEGAL.

YOU MAY NOT HAVE AN ELSE PART WITH A DELAY, SINCE THE DELAY WOULD NEVER BE ACCEPTED.

SELECT WITH DELAY ALTERNATIVE
(WAIT A FINITE TIME)

```
TASK BODY T1 IS
BEGIN
  LOOP
    SELECT
      ACCEPT ENTRY1 DO....
    [OR
      ACCEPT ENTRY2.....]
    OR
      DELAY <EXPRESSION>;
      <SOS>;
    OR
      DELAY <EXPRESSION>;
      <SOS>;

    --SHORTEST DELAY WILL GET CHOSEN

    END SELECT;
  END LOOP;
END T1;
```

GUARDS CAN BE USED ON ANY ACCEPT
STATEMENT

```
...
...
...
  WHEN SOME_CONDITION =>
     ACCEPT ENTRY1 ......
```

IF THERE IS NO GUARD, THE ACCEPT STATEMENT IS SAID TO BE OPEN.

IF THERE IS A GUARD, AND THE WHEN CONDITION IS TRUE, THE ACCEPT IS ALSO OPEN.

FALSE GUARD STATEMENTS ARE SAID TO BE CLOSED.

OPEN ALTERNATIVES ARE CONSIDERED. IF THERE IS MORE THAN ONE, THEN ONE IS SELECTED ARBITRARILY.

IF THERE ARE NO OPEN ALTERNATIVES (AND NO ELSE PART), THE EXCEPTION PROGRAM_ERROR IS RAISED.

TERMINATION

WHEN A TASK HAS COMPLETED ITS SEQUENCE OF STATEMENTS, ITS STATUS IS COMPLETED

ADDITIONALLY, THERE IS AN OPTION THAT ALLOWS A TASK TO TERMINATE.

```
SELECT
  ACCEPT ENTRY1 DO .....
[OR
  ACCEPT ENTRY2 DO.....]
 OR
  TERMINATE;
END SELECT;
```

THIS MAY NOT BE USED WITH EITHER THE THE DELAY OR AN ELSE CLAUSE.

SINCE THIS IS USED ONLY WITH A 'WAIT FOREVER' TASK, THIS OPTION ALLOWS A TASK THAT IS WAITING FOREVER TO TERMINATE IF ITS PARENT IS ALSO READY TO QUIT.

REMEMBER....

Tasks are Non-deterministic

```
select
    accept ENTRY1;
or
    accept ENTRY2;
```

Might always take ENTRY1!!!!

KILLING A TASK

OFTEN, A 'TERMINATE' ALTERNATIVE IS NOT SUFFICIENT.

A PARENT MAY KILL DEPENDENT TASKS (OR ITSELF) USING THE ABORT STATEMENT.

THIS SHOULD ONLY BE USED IN VERY RARE CIRCUMSTANCES.

A BETTER METHOD IS TO USE AN ENTRY TO 'ACCEPT' A SHUTDOWN CALL.

IF YOU HAVE ACCEPTED A 'SHUTDOWN' CALL, THEN IT IS OK TO ABORT YOURSELF.

```
TASK BODY T1 IS
BEGIN
 LOOP       -- THE ENDLESS LOOP OF THE
            --  TASK STARTS HERE
            -- EXIT LOOP TO TERMINATE
   SELECT
            -- THE REQUIRED ACCEPT
            --  STATEMENTS ARE CODED HERE
   OR
            ACCEPT SHUTDOWN;
            --SPECIAL FINAL ACTIONS HERE
            EXIT; -- EXITS LOOP, ENDS TASK
   OR
            TERMINATE; -- FOR CASES WHERE
                  -- SHUTDOWN NOT CALLED
   END SELECT;
 END LOOP;
END T1;
```

PROBLEMS WITH PARALLELISM

MULTIPLE 'THREADS OF CONTROL' CAN CAUSE PROBLEMS IF TWO PROCESSES ARE TRYING TO ACCESS AND UPDATE ONE PIECE OF INFORMATION AT THE SAME TIME.

```
PRAGMA SHARED
      MY-OBJECT : SOME-TYPE;
      PRAGMA SHARED (MY-OBJECT);
```

ENFORCES MUTUALLY EXCLUSIVE ACCESS

ONLY WORKS FOR SCALAR AND ACCESS TYPES

SEMAPHORES CAN ALSO BE USED TO CONTROL ACCESS TO AN OBJECT

-PROMOTES 'POLLING'

ENCAPSULATING A DATA ITEM WITHIN A TASK IS A BETTER METHOD

```
TASK SEMAPHORE IS
    ENTRY P; --GET RESOURCE
    ENTRY V; --RELEASE
END SEMAPHORE;

TASK BODY SEMAPHORE IS
     AVAILABLE : BOOLEAN := TRUE;
BEGIN
    LOOP
        SELECT
            WHEN AVAILABLE
            ACCEPT P DO
                 AVAILABLE := FALSE;
            END P;
        OR
            WHEN NOT AVAILABLE
            ACCEPT V DO
                 AVAILABLE := TRUE;
            END V;
        OR
            TERMINATE;
    END LOOP;
END SEMAPHORE;
```

```
TASK SPECIAL_OPS IS
   ENTRY ASSTGN ( OBJECT : IN SOME_TYPE );
   ENTRY RETRIEVE ( OBJECT : OUT SOME_TYPE);
END SPECIAL_OPS;


 TASK BODY SPECIAL_OPS IS
      THE_OBJECT : SOME_TYPE;
      BEGIN
         LOOP
           SELECT
            ACCEPT ASSIGN(OBJECT:IN SOME_TYPE)DO
               THE_OBJECT := OBJECT;
             END ASSIGN;
          OR
            ACCEPT RETRIEVE(OBJECT:OUT SOME_TYPE)DO
               OBJECT := THE_OBJECT;
            END RETRIEVE;
          OR
            TERMINATE;
           END SELECT;
         END LOOP;
END SPECIAL_OPS;
```

CALLING A TASK ENTRY

WHEN YOU CALL A TASK, YOU MUST KNOW THE TASK NAME.

THERE ARE THREE TYPES

ENTRY CALLS (WAIT FOREVER)

TIMED ENTRY CALLS (WAIT FOR SPECIFIED TIME)

CONDITIONAL ENTRY CALLS (DON'T WAIT AT ALL)

CALL AND WAIT FOREVER

TO CALL AN ENTRY, SPECIFY THE
TASK NAME AND THEN THE ENTRY NAME

```
BEGIN
 ...
   T1.ENTRY1(DATA);
```

TIMED ENTRY CALL
(WAIT FOR A FINITE TIME)

```
SELECT
   T1.ENTRY1(DATA);
      <SOS>
OR
   DELAY 60;
   <SOS>
END SELECT;
```

YOU CANNOT USE AN 'OR' TO CALL TWO (OR MORE) TASK ENTRIES!!!

THIS WOULD BE EQUIVALENT TO STANDING IN TWO DIFFERENT LINES AT ONCE.

CONDITIONAL ENTRY CALLS
(DON'T WAIT AT ALL)

```
SELECT
   T1.ENTRY1(DATA);
   <SOS>
ELSE
   <SOS>
END SELECT;
```

NOTICE THE 'ORTHOGONALITY' OR THE SELECT STATEMENT. IT IS USED IN EITHER A TASK ENTRY CALL OR AN ACCEPT STATEMENT.

ALSO NOTICE THAT INSTEAD OF
'ACCEPT...BEGIN...END ACCEPT;
IT IS
'ACCEPT...DO....END ENTRY_NAME;

WHY???

TASK ATTRIBUTES

T'CALLABLE - RETURNS BOOLEAN VALUE
TRUE -TASK CALLABLE,
FALSE -TASK COMPLETED,
ABNORMAL OR TERMINATED

T'TERMINATED - BOOLEAN VALUE
TRUE IF TERMINATED

E'COUNT - RETURNS AN UNIVERSAL
INTEGER INDICATING THE
NUMBER OF ENTRY CALLS
QUEUED FOR ENTRY E.

-AVAILABLE ONLY WITHIN
TASK T ENCLOSING E

TASK PRIORITIES

PRAGMA PRIORITY (STATIC_EXPRESSION);

USED TO REPRESENT DEGREE OF RELATIVE URGENCY.

IF TWO TASKS ARE READY, THEN THE TASK WITH THE HIGHER PRIORITY RUNS.

ALTHOUGH PRIORITIES ARE STATIC, TASK RENDEZVOUS ARE DYNAMIC. WHEN TASKS ARE IN RENDEZVOUS, THE PRIORITY IS THE HIGHER OF THE CALLER AND THE CALLEE.

SYNCHRONIZATION OF DATA

```
TASK SYNC IS
   ENTRY UPDATE ( DATA : IN DATA_TYPE);
   ENTRY READ   ( DATA :OUT DATA_TYPE);
END SYNC;

TASK BODY SYNC IS
  LOCAL : DATA_TYPE;
  BEGIN
    LOOP

      SELECT
         ACCEPT UPDATE(DATA : IN DATA_TYPE) DO
            LOCAL := DATA;
         END UPDATE;
      OR
         TERMINATE;
      END SELECT;

      SELECT
         ACCEPT READ (DATA : OUT DATA_TYPE) DO
            DATA := LOCAL;
         END READ;
      OR
         TERMINATE;
      END SELECT;

    END LOOP;
  END SYNC;
```

FAMILIES OF ENTRIES

```
TYPE URGENCY IS (LOW, MEDIUM, HIGH);

TASK MESSAGE IS
     ENTRY RECEIVE(URGENCY) (DATA : DATA_TYPE);
END MESSAGE;

TASK BODY MESSAGE IS
  BEGIN
    LOOP
      SELECT
        ACCEPT RECEIVE(HIGH) (DATA:DATA_TYPE) DO
          ...
        END RECEIVE;
      OR
        WHEN RECEIVE(HIGH)'COUNT = 0 =>
        ACCEPT RECEIVE(MEDIUM) (DATA:DATA_TYPE) DO
          ...
        END RECEIVE;
      OR
        WHEN RECEIVE(HIGH)'COUNT+RECEIVE(MEDIUM)'COUNT=0 =>
        ACCEPT RECEIVE(LOW) (DATA:DATA_TYPE) DO
          ...
        END RECEIVE;
      OR
        DELAY 1.0; -- SHORT WAIT
   END MESSAGE;
```

SAME THING, WITH NO GUARDS

```
TYPE URGENCY IS (LOW, MEDIUM, HIGH);

TASK MESSAGE IS
     ENTRY RECEIVE(URGENCY) (DATA : DATA_TYPE);
END MESSAGE;

TASK BODY MESSAGE IS
  BEGIN
    LOOP
      SELECT
           ACCEPT RECEIVE(HIGH) (DATA:DATA_TYPE) DO
           ...
           END RECEIVE;
      ELSE
           SELECT
              ACCEPT RECEIVE(MEDIUM) (DATA:DATA_TYPE) DO
              ...
              END RECEIVE;
           ELSE
              SELECT
                 ACCEPT RECEIVE(LOW) (DATA:DATA_TYPE) DO
                 ...
                 END RECEIVE;
              OR
                 DELAY 1.0; -- SHORT WAIT
             END SELECT;
          END SELECT;
      END SELECT;
   END MESSAGE;
```

LENGTH CLAUSE

T'STORAGE_SIZE

```
TASK TYPE T1 IS
    ENTRY ENTRY_1;
    FOR T1'STORAGE_SIZE USE
            2000*SYSTEM.STORAGE_UNIT);
END T1;
```

THE PREFIX T DENOTES A TASK TYPE.

THE SIMPLE EXPRESSION MAY BE STATIC, AND IS USED TO SPECIFY THE NUMBER OS STORAGE UNITS TO BE RESERVED OR FOR EACH ACTIVATION (NOT THE CODE) OF THE TASK.

ADDRESS CLAUSE

```
TASK TYPE T1 IS
     ENTRY ENTRY_1;
     FOR T1 USE AT 16#167A#;
END T1;
```

IN THIS CASE, THE ADDRESS SPECIFIES THE ACTUAL LOCATION IN MEMORY WHERE THE MACHINE CODE ASSOCIATED WITH T1 WILL BE PLACED.

```
TASK T1 IS
     ENTRY ENTRY_1;
     FOR ENTRY_1 USE AT 16#40#;
END T1;
```

IF THIS CASE, ENTRY_1 WILL BE MAPPED TO HARDWARE INTERRUPT 64.

ONLY IN PARAMETERS CAN BE ASSOCIATED WITH INTERRUPT ENTRIES.

AN INTERRUPT WILL ACT AS AN ENTRY CALL ISSUED BY THE HARDWARE, WITH A PRIORITY HIGHER THAN ANY USER-DEFINED TASK.

DEPENDING UPON THE IMPLEMENTATION, THERE CAN BE MANY RESTRICTIONS UPON THE TYPE OF CALL TO THE INTERRUPT, AND UPON THE TERMINATE ALTERNATIVES.

NOTE: YOU CAN DIRECTLY CALL AN INTERRUPT ENTRY.

TASKS AT DIFFERENT PRIORITIES

GIVEN 5 TASKS, 3 OF VARYING PRIORITY, 1 TO BE INTERRUPT DRIVEN, AND 1 THAT WILL BE TIED TO THE CLOCK.

```
PROCEDURE HEAVY_STUFF IS

   TASK HIGH_PRIORITY IS
        PRAGMA PRIORITY(50);  --OR AS HIGH AS SYSTEM ALLOWS
        ENTRY POINT;
   END HIGH_PRIORITY;

   TASK MEDIUM_PRIORITY IS
        PRAGMA PRIORITY(25);
        ENTRY POINT;
   END MEDIUM_PRIORITY;

   TASK LOW_PRIORITY IS
        PRAGMA PRIORITY(1);
        ENTRY POINT;
   END LOW_PRIORITY;

   TASK INTERRUPT_DRIVEN IS
        ENTRY POINT;
        FOR POINT USE AT 16#61#; --INTERRUPT 97
   END INTERRUPT_DRIVEN;

   TASK CLOCK_DRIVEN IS
        --THERE ARE TWO WAYS TO DO THIS

        --FIRST WAY IS TO HAVE ANOTHER TASK MONITOR
        -- THE CLOCK, AND CALL CLOCK_DRIVEN.CALL
        -- EVERY TIME UNIT.
        ENTRY CALL;

        --SECOND WAY IS TO ACTUALLY TIE CALL TO AN
        -- CLOCK INTERRUPT, AND LET CALL DETERMINE WHEN
        -- HE WISHES TO PERFORM AN ACTION
        FOR CALL USE AT 16#32#; --ASSUME INTERRUPT 50
                                -- IS A CLOCK INTERRUPT
     END CLOCK_DRIVEN;
END HEAVY_STUFF;
```

```
TASK QUEUE IS
    ENTRY INSERT(DATA : IN DATA_TYPE);
    ENTRY REMOVE(DATA :OUT DATA_TYPE);
END QUEUE;

TASK BODY QUEUE IS
   HEAD,TAIL : INTEGER := 0;
   Q : ARRAY (1..100) OF DATA_TYPE;
   BEGIN
     LOOP
       SELECT
         WHEN TAIL - HEAD + 1 /= 0 AND THEN
              TAIL - HEAD + 1 /= 100 =>
         ACCEPT INSERT(DATA : IN DATA_TYPE) DO
              IF HEAD = 0 THEN HEAD := 1; END IF;
              IF TAIL = 100 THEN TAIL := 0; END IF;
              TAIL := TAIL + 1;
              Q(TAIL) := DATA;
         END INSERT;
       OR
         WHEN HEAD /= 0 =>
         ACCEPT REMOVE(DATA :OUT DATA_TYPE) DO
              DATA := Q(HEAD);
              IF HEAD = TAIL THEN
                 HEAD := 0;
                 TAIL := 0;
              ELSE
                 HEAD := HEAD + 1;
                 IF HEAD > 100 THEN HEAD := 1; END IF;
              END IF;
          END REMOVE;
       OR
          TERMINATE;
       END SELECT;
     END LOOP;
   END QUEUE;
```

```
TASK TYPE QUEUE IS
    ENTRY INSERT(DATA : IN DATA_TYPE);
    ENTRY REMOVE(DATA :OUT DATA_TYPE);
END QUEUE;

TASK BODY QUEUE IS
   HEAD,TAIL : INTEGER := 0;
   Q : ARRAY (1..100) OF DATA_TYPE;
   BEGIN
     LOOP
       SELECT
         WHEN TAIL - HEAD + 1 /= 0 AND THEN
              TAIL - HEAD + 1 /= 100 =>
         ACCEPT INSERT(DATA : IN DATA_TYPE) DO
              IF HEAD = 0 THEN HEAD := 1; END IF;
              IF TAIL = 100 THEN TAIL := 0; END IF;
              TAIL := TAIL + 1;
              Q(TAIL) := DATA;
         END INSERT;
       OR
         WHEN HEAD /= 0 =>
         ACCEPT REMOVE(DATA :OUT DATA_TYPE) DO
              DATA := Q(HEAD);
              IF HEAD = TAIL THEN
                 HEAD := 0;
                 TAIL := 0;
              ELSE
                 HEAD := HEAD + 1;
                 IF HEAD > 100 THEN HEAD := 1; END IF;
              END IF;
           END REMOVE,
       OR
           TERMINATE;
       END SELECT;
     END LOOP;
   END QUEUE;

   MY_QUEUE, YOUR_QUEUE : QUEUE, -- TWO TA[illegible]
```

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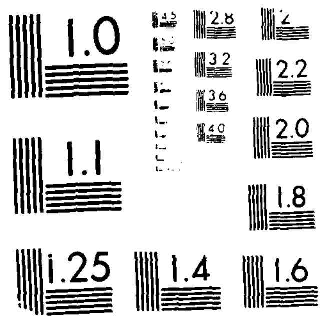

MICROCOPY RESOLUTION TEST CHART

```
GENERIC
DATA_TYPE : PRIVATE;
QUEUE_SIZE: POSITIVE := 100;

PACKAGE QUEUE_PACK IS

TASK QUEUE IS
    ENTRY INSERT(DATA : IN DATA_TYPE);
    ENTRY REMOVE(DATA :OUT DATA_TYPE);
END QUEUE;

PACKAGE BODY QUEUE_PACK IS
TASK BODY QUEUE IS
   HEAD,TAIL : INTEGER := 0;
   Q : ARRAY (1..QUEUE_SIZE) OF DATA_TYPE;
   BEGIN
     LOOP
       SELECT
         WHEN TAIL - HEAD + 1 /= 0 AND THEN
              TAIL - HEAD + 1 /= QUEUE_SIZE =>
         ACCEPT INSERT(DATA : IN DATA_TYPE) DO
              IF HEAD = 0 THEN HEAD := 1; END IF;
              IF TAIL = QUEUE_SIZE THEN TAIL := 0; END IF;
              TAIL := TAIL + 1;
              Q(TAIL) := DATA;
         END INSERT;
       OR
         WHEN HEAD /= 0 =>
         ACCEPT REMOVE(DATA :OUT DATA_TYPE) DO
              DATA := Q(HEAD);
              IF HEAD = TAIL THEN
                 HEAD := 0;
                 TAIL := 0;
              ELSE
                 HEAD := HEAD + 1;
                 IF HEAD> QUEUE_SIZE THEN HEAD := 1; END IF;
              END IF;
          END REMOVE;
       OR
          TERMINATE;
       END SELECT;
     END LOOP;
   END QUEUE;


PACKAGE NEW_QUEUE IS NEW QUEUE_PACK(MY_RECORD, 250);
PACKAGE OLD_QUEUE IS NEW QUEUE_PACK(INTEGER);
```

```
PROCEDURE INSERT_INTEGER (DATA : IN INTEGER ) RENAMES
    OLD_QUEUE.INSERT;

PROCEDURE REMOVE_INTEGER (DATA :OUT INTEGER ) RENAMES
    OLD_QUEUE.REMOVE;
```

```
PROCEDURE SPIN (R : RESOURCE) IS
BEGIN
  LOOP
    SELECT
       R.SEIZE;
       RETURN;
    ELSE
       NULL;  --BUSY WAITING
    END SELECT;
  END LOOP;
END;
```

--OR--

```
PROCEDURE SPIN (R : RESOURCE) IS
BEGIN
   R.SEIZE;
   RETURN;
END;
```

ADA TASKING

SCENARIO I

"THE GOLDEN ARCHES"

MCD TASKS :

- SERVICE PROVIDED : FOOD
- SERVICE REQUESTED : NONE

GONZO TASKS :

- SERVICE PROVIDED : NONE
- SERVICE REQUESTED : FOOD

```
Task McD is
    entry SERVE(TRAY_OF : out FOOD_TYPE);
end McD;

Task GONZO;

Task Body McD is
    NEW_TRAY : FOOD_TYPE;
    function COOK return FOOD_TYPE is ......;
    begin
        loop
            accept SERVE(TRAY_OF : out FOOD_TYPE) do
                TRAY_OF := COOK;
            end;
        end loop;
    end McD;
```

```
Task Body GONZO is
    MY_TRAY : FOOD_TYPE;

    procedure CONSUME(MY_TRAY:in FOOD_TYPE) is ...

    begin
        loop
            McD.SERVE ( MY_TRAY);
            CONSUME(MY_TRAY);
        end loop;
    end GONZO;
```

```
Task Body McD is
    NEW_TRAY : FOOD_TYPE;

    function COOK return FOOD_TYPE is
        ...
    end COOK;

    begin
        loop
            NEW_TRAY := COOK;
            accept SERVE(TRAY_OF:out FOOD_TYPE) do
                TRAY_OF := NEW_TRAY;
            end SERVE;
        end loop;
    end GONZO;
```

```
loop
    NEW_TRAY := COOK;
    select
        accept SERVE(TRAY_OF : out FOOD_TYPE) do
            TRAY_OF := NEW_TRAY;
        end SERVE;
    else
        null;
    end select;
end loop;
```

```
loop
    NEW_TRAY := COOK;
    select
        accept SERVE(TRAY_OF : out FOOD_TYPE) do
            TRAY_OF := NEW_TRAY;
        end SERVE;
    else
        terminate;
    end select;
end loop;
```

```
loop
   NEW_TRAY := COOK;
   select
      accept SERVE(TRAY_OF : out FOOD_TYPE) do
         TRAY_OF := NEW_TRAY;
      end SERVE;
   or
      delay 15.0 * MINUTES;
   end select;
end loop;
```

```
loop

    select
        McD.SERVE(MY_ORDER);  CONSUME(MY_ORDER);
    else
        select
            BK.SERVE(MY_ORDER); CONSUME (MY_ORDER);
        else
            exit;
        end select;
    end select;

end loop;
```

```
loop

    select
        McD.SERVE(MY_ORDER);  CONSUME(MY_ORDER);
    or
        delay 5.0 * MINUTES;
        select
            BK.SERVE(MY_ORDER); CONSUME (MY_ORDER);
        or
            delay 5.0 * MINUTES;
            exit;
        end select;
    end select;

end loop;
```

```
loop

    select
        McD.SERVE (MY_ORDER);
    or                                        --**
        BK.SERVE(MY_ORDER);
    end select;

    CONSUME(MY_ORDER);

end loop;
```

```
loop

    select
        McD.SERVE (MY_ORDER);
    or                                          --**
        BK.SERVE(MY_ORDER);
    else
        delay 10.0 * MINUTES;
        exit;
    end select;

    CONSUME(MY_ORDER);

end loop;
```

ADA TASKING

SCENARIO II

"NO FREE LUNCH"

MCD TASK

SERVICE PROVIDED : FOOD
SERVICE REQUESTED: MONEY

GONZO TASK

SERVICE PROVIDED : MONEY
SERVICE REQUESTED: FOOD

```
Task McD is
    entry SERVE(ORDER: out FOOD_TYPE;
                COST: in  MONEY_TYPE);
end McD;

Task GONZO;



--OR

Task McD is
    entry SERVE(ORDER: out FOOD_TYPE);
end McD;

Task GONZO is
    entry PAY (COST : in MONEY_TYPE;
               PAYMENT : out MONEY_TYPE);
end GONZO;
```

```
Task Body McD is
   CASH_DRAWER, AMOUNT_PAID: MONEY_TYPE;
   NEW_ORDER  : FOOD_TYPE;
   function COOK ..........
   function CALC_COST(ORDER: in FOOD_TYPE)
      return MONEY_TYPE .........

   begin
      loop
         NEW_ORDER := COOK;
         select
            accept SERVE(ORDER:out FOOD_TYPE) do
               ORDER := NEW_ORDER;
               COST := CALC_COST(NEW_ORDER);
               GONZO.PAY(COST, AMOUNT_PAID); --**
               CASH_DRAWER :=
                  CASH_DRAWER + AMOUNT_PAID;
            end SERVE;
         or
            delay 15.0 * MINUTES;
         end select;
      end loop;
   end McD;
```

```
Task Body GONZO IS
    ACCOUNT_BALANCE : MONEY_TYPE;
    MY_ORDER : FOOD_TYPE;
    function GO_TO_WORK return MONEY_TYPE ......

    begin
        ACCOUNT_BALANCE :=
            ACCOUNT_BALANCE + GO_TO_WORK;
        loop
            McD.SERVE(MY_ORDER);
            accept PAY (COST : in MONEY_TYPE;
                        PAYMENT:out MONEY_TYPE) do
                ACCOUNT_BALANCE :=
                    ACCOUNT_BALANCE - COST;
                PAYMENT := COST;
            end PAY;
        end loop;
    end GONZO;
```

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Ada Tas ing

Scenario II a

"No Wait for the Waiters"

McD Task
- Service Provided : Food
- Service Requested: Money

Gonzo Task
- Service Provided : Money
- Service Requested: Food

Manager Task
- Service Provided : Make new Waiter
- Service Requested: None

```
Task type McD is
    entry SERVE.....
end McD;

Task GONZO is
    entry PAY.....
end GONZO;

Task MANAGER;

Type CASHIER_POINTER is access McD;

Type REGISTER_TYPE is array (1..NO_REGISTERS)
                   of CASHIER_POINTER;

THE_REGISTERS : REGISTER_TYPE
                         := (others => new McD);
```

+

```
Task Body McD is
    ...
    ...
    ...
    begin
        loop
            NEW_ORDER := COOK;
            select
                accept SERVE.....
                ...
                end SERVE;
            or
                delay 2.0 * MINUTES;
                exit;
            end select;
        end loop;
```

```
Task Body GONZO is
    ...
    ...
    begin
        ...
        ...
        --- Now, GONZO has to search for the open
        ---  registers, and select the one with
        ---  the shortest line
        ...
        ...
        THE_REGISTERS(MY_REGISTER).SERVE...
        ...
    end GONZO;
```

```
Task Body MANAGER is
    ...
    ...
    begin
        loop
        --The Manager will look at the queue lengths of
        --  the open registers, and, when necessary,
        --  will open registers that are currently
        --  closed
        ...
        ...
            if ...........then
                THE_REGISTERS(CLOSED_REGISTER):=
                                                        new McD;
            end if;
        end loop;
    end MANAGER;
```

ADA TAS ING

SCENARIO III

"A SUGAR CONE, PLEASE:

BR TASK
SERVICE PROVIDED : ICE CREAM
SERVICE REQUESTED: AN ORDER

SERVOMATIC TASK
SERVICE PROVIDED : A NUMBER

CUSTOMERS TASK
SERVICE PROVIDED : AN ORDER
SERVICE REQUESTED: ICE CREAM

```
Task BR is
    entry SERVE(ICE_CREAM: out DESSERT_TYPE;
end BR;

Task SERVOMATIC is
    entry TAKE(A_NUMBER: out SERVOMATIC_NUMBERS);
end SERVOMATIC;

Task type CUSTOMER_TASK is
    entry REQUEST(ORDER: out ORDER_TYPE);
enter CUSTOMER_TASK;

Type CUSTOMER is access CUSTOMER_TASK;

CUSTOMERS : array (SERVOMATIC_NUMBERS) of CUSTOMER;
```

```
Task Body BR is
   NEXT_CUSTOMER : SERVOMATIC_NUMBERS :=
                         SERVOMATIC_NUMBERS'last;
   CUREENT_ORDER : ORDER_TYPE;
   ICE_CREAM : DESSERT_TYPE;
   function MAKE(ORDER : in ORDER_TYPE) return
                      DESSERT_TYPE is ......
   begin
     loop
         begin
           NEXT_CUSTOMER:=(NEXT_CUSTOMER+1)
                       mod SERVOMATIC_NUMBERS'last;
           CUSTOMERS(NEXT_CUSTOMER).REQUEST
                                   (CURRENT_ORDER);
           ICE_CREAM := MAKE (CURRENT_ORDER);
           accept SERVE(ICE_CREAM:out DESSERT_TYPE) do
               ICE_CREAM := BR.ICE_CREAM;
           end SERVE;
         exception
           when TASKING_ERROR=>null;--customer not here
         end;
     end loop
   end;
```

```
Task Body SERVOMATIC is
   NEXT_NUMBER : SERVOMATIC_NUMBERS :=
                    SERVOMATIC_NUMBERS'first;

   begin
     loop
       accept TAKE(A_NUMBER:out SERVOMATIC_NUMBERS)d
           A_NUMBER := NEXT_NUMBER;
       end TAKE;
       NEXT_NUMBER:=(NEXT_NUMBER + 1) mod
                         SERVOMATIC_NUMBERS'last;
     end loop;

   end SERVOMATIC;
```

```
Task Body CUSTOMER_TASK is
    MY_ORDER : ORDER_TYPE := ...  -- some value
    MY_DESSERT : DESSERT_TYPE;

    begin
        accept REQUEST(ORDER:out ORDER_TYPE) do
            ORDER := MY_ORDER;
        end REQUEST;
        BR.SERVE(MY_DESSERT);
        --eat the dessert, or do whatever
    end;
```

ADA TASKING

SCENARIO IV

"LETS HIDE THE SPOOLER TASK"

PRINTER_PACKAGE
ACTION-"HIDES" THE PRINT SPOOLER
BY RENAMING TASK ENTRY

SPOOLER TASK
SERVICE PROVIDED : VIRTUAL PRINT
SERVICE REQUESTED: PHYSICAL PRINT

PRINTER TASK
SERVICE PROVIDED : PHYSICAL PRINT
SERVICE REQUESTED: FILE NAME

```
Package PRINTER_PACKAGE is
    ...
    ...
    task SPOOLER is
        entry PRINT_FILE(NAME : in STRING;
                         PRIORITY : in NATURAL);
        entry PRINTER_READY;
    end SPOOLER;
    ...
    ...
    procedure PRINT (NAME : in STRING;
                     PRIORITY : in NATURAL := 10)
            renames SPOOLER.PRINT_FILE;
    end PRINTER_PACKAGE;


    Package Body PRINTER_PACKAGE is
        ...
        task PRINTER is
            entry PRINT_FILE(NAME : in STRING);
        end PRINTER;
        ...
    end PRINTER_PACKAGE;
```

```
Task Body SPOOLER is
    begin
        loop
            select
                accept PRINTER_READY do
                    PRINTER.PRINT_FILE(REMOVE(QUEUE));
                    --Remove would determine the next job
                    -- and send it to the actual printer
                end PRINTER_READY;
            else
                null;
            end select;

            select
                accept PRINT_FILE(NAME : in STRING;
                                  PRIORITY : NATURAL ) do
                    INSERT (NAME, PRIORITY);
                    --put name on queue or queues
                    --  according to priority
                end PRINT_FILE;
            else
                null;
            end select;
        end loop;
    end SPOOLER:
```

```
Task Body PRINTER is
    begin
        loop
            SPOOLER.PRINTER_READY;
            accept PRINT_FILE (NAME : in STRING) do

                if NAME'length /= 0 then .....

                    -- print the file


                else
                    delay 10.0 * SECONDS;
                end if;

            end PRINT_FILE;
        end loop;

    end PRINTER;
```

```
with PRINTER_PACKAGE;

procedure MAIN is
    ...
    ...
    ...
    loop
        -- process several files

        PRINTER_PACKAGE.PRINT (A_FILE, A_PRIORITY);
        ...
        ...
    end loop;
end MAIN;
```

+

TASKING MINDSET

SIMPLE PROBLEM - WRITE A TASK SPEC TO LET TASK A SEND AN INTEGER TO TASK B.

SOLUTION 1 - A CALLS AN ENTRY IN B

SOLUTION 2 - B CALLS FOR AN ENTRY IN A

SOLUTION 3 - WRITE A 'BUFFER' TASK
TO CALL ENTRY IN A, GET INTEGER, AND
THEN CALL ENTRY IN B TO SEND INTEGER

SOLUTION 4 - WRITE BUFFER TASK C TO
ACCEPT INTEGERS FROM A, AND ALSO
ACCEPT REQUESTS FROM B

IN-CLASS EXERCISE

LET US DESIGN THE TASK SPECIFICATIONS FOR THE FOLLOWING SENARIO.

THREE TASKS HAVE ACCES TO A TYPE KNOWN AS MESSAGE_TYPE.

TASK_1 PRODUCES MESSAGES. TASK_2 CAN RECEIVE MESSAGES, HOLD THEM IN A BUFFER (IF NECESSARY), AND SENDS THEM TO TASK_3 WHEN THE DATE/TIME FIELD (PART OF MESSAGE_TYPE) SAYS TO.

```
TASK TASK_1 IS



END TASK_1;



TASK TASK_2 IS



END TASK_2;



TASK TASK_3 IS



END TASK_3;
```

TASKING EXERCISE

WRITE A MAIN PROGRAM AND TWO TASKS TO SIMULATE A HOUSE ALARM SYSTEM. THE MAIN PROGRAM IS AN INPUT SIMULATOR TO THE TASKS. ONE TASK KEEPS TRACK OF THE STATUS OF THE HOUSE. ANOTHER IS THE ACTUAL ALARM SYSTEM.

TASK 1: THE HOUSE STATUS (TASK NAME :HOUSE)
THREE ENTRIES => OK, NOT_OK, WRITE

THE ENTRIES OK AND NOT_OK SET OR RESET A FLAG THAT DETERMINES THE STATUS OF THE HOUSE. NOT_OK WILL ALSO SET A VARIABLE TO TELL YOU WHICH ALARM IS CURRENTLY GOING OFF. BOTH OK AND NOT_OK SHOULD PRINT OUT A MESSAGE VERIFYING THAT THEY WERE CALLED. THE WRITE ENTRY WILL PRINT THE STATUS OF THE HOUSE. IF THERE IS AN ALARM CURRENTLY GOING OFF, WRITE WILL TELL YOU THE ALARM NUMBER.

TASK 2: THE ALARM SYSTEM (TASK NAME: ALARM)
THREE ENTRIES => FIRE, INTRUDER, SHUTOFF

THE ALARM SYSTEM WILL ACCEPT ANY OF THE THREE ENTRY CALLS FROM THE INPUT SIMULATOR. IF THERE ARE NO ENTRY CALLS WITHIN 5 SECONDS, IT WILL CALL HOUSE.WRITE TO DISPLAY THE STATUS. FIRE AND INTRUDER EACH HAVE A PARAMETER INDICATION THE ALARM LOCATION. FIRE LOCATIONS ARE '1' THRU '9'. INTRUDER LOCATIONS ARE 'A' THRU 'Z'. FIRE AND INTRUDER SHOULD CALL HOUSE.NOT_OK (AND TELL THE HOUSE WHERE THE ALARM IS SOUNDING), AND THEN PRINT OUT A MESSAGE

MAIN PROGRAM

THE MAIN PROGRAM WILL READ IN CHARACTERS FROM THE KEYBOARD. IF THE CHARACTER IS A '1' THRU '9', CALL THE FIRE ALARM. IF THE CHARACTER IS A 'A' THRU 'Z' THEN IT CALLS THE INTRUDER ALARM. IF THE CHARACTER IS A '0'(ZERO), THE HOUSE IS RESET TO OK. IF THE CHARACTER IS A '!', THEN THE ALARM IS SHUTDOWN, AND THE PROGRAM ENDS. ALL OTHER CHARACTERS DO NOTHING.

THE HOUSE STATUS SHOULD BE OK TO START.

```
run cookie


The house is ok


The house is ok

&
Invalid character.  Try again


The house is ok

G
House alarm set to not OK at location G
Intruder in room G

The house is not ok ..alarm is off at location G


The house is not ok ..alarm is off at location G

4
House alarm set to not OK at location 4
Fire Alarm # 4 has been set off.

The house is not ok ..alarm is off at location 4

0
House alarm reset to OK.

The house is ok


The house is ok

!
The alarm has been turned off

*)
```

```
WI.H TEXT_IO;
USE TEXT_IO;

PROCEDURE COOKIE  IS

CHAR : CHARACTER;

    TASK HOUSE  IS
        ENTRY OK;
        ENTRY NOT_OK (WHERE:CHARACTER);
        ENTRY WRITE;
    END HOUSE ;

    TASK ALARM  IS
        ENTRY FIRE     (LOCATION:CHARACTER);
        ENTRY INTRUDER (LOCATION:CHARACTER);
        ENTRY SHUTOFF;
    END ALARM ;
```

```
TASK BODY HOUSE  IS
    TYPE CONDITION IS (OK, NOT_OK);
    ALARM_STATUS : CONDITION := OK;
    ALARM_LOCATION : CHARACTER;

BEGIN
    LOOP
        SELECT
            ACCEPT OK DO
                ALARM_STATUS := OK;
                PUT_LINE("HOUSE ALARM RESET TO OK.");
            END OK;
        OR
            ACCEPT NOT_OK (WHERE:CHARACTER) DO
                ALARM_STATUS := NOT_OK;
                ALARM_LOCATION := WHERE;
                PUT_LINE("HOUSE ALARM SET TO NOT OK AT"&
                    "LOCATION " & ALARM_LOCATION);
            END NOT_OK;
        OR
            ACCEPT WRITE DO
                NEW_LINE;
                CASE ALARM_STATUS IS
                  WHEN OK =>PUT_LINE("THE HOUSE IS OK");
                  WHEN NOT_OK =>  PUT_LINE
                       ("THE HOUSE IS NOT OK"&
                        " ..ALARM IS OFF AT LOCATION " &
                         ALARM_LOCATION);
                END CASE;
                NEW_LINE;
            END WRITE;
        OR
            TERMINATE;
        END SELECT;
    END LOOP;
END HOUSE ;
```

```
TASK BODY ALARM  IS
BEGIN
    LOOP
        SELECT
            ACCEPT FIRE (LOCATION:CHARACTER) DO
                HOUSE.NOT_OK(LOCATION);
                PUT ("FIRE ALARM # ");
                PUT (LOCATION);
                PUT_LINE (" HAS BEEN SET OFF.");
            END FIRE;
        OR
            ACCEPT INTRUDER (LOCATION:CHARACTER) DO
                HOUSE.NOT_OK(LOCATION);
                PUT ("INTRUDER IN ROOM ");
                PUT (LOCATION);
                NEW_LINE;
            END INTRUDER;
        OR
            ACCEPT SHUTOFF;
            PUT_LINE ("THE ALARM HAS BEEN TURNED OFF");
            EXIT;
        OR
            DELAY 5.0;
            HOUSE.WRITE;
        END SELECT;
    END LOOP;
END ALARM;
```

```
BEGIN        --MAIN
    LOOP
        GET (CHAR);
        SKIP_LINE;
        CASE CHAR IS
            WHEN '1' .. '9' =>  ALARM.FIRE (CHAR);
            WHEN 'a' .. 'z' =>  ALARM.INTRUDER (CHAR);
            WHEN 'A' .. 'Z' =>  ALARM.INTRUDER (CHAR);
            WHEN '0'        =>  HOUSE.OK;
            WHEN '!'        =>  ALARM.SHUTOFF;
            WHEN OTHERS     =>  PUT_LINE
                      ("INVALID CHARACTER.  TRY AGAIN");
        END CASE;
        EXIT WHEN CHAR = '!';
    END LOOP;

END COOKIE;
```

Tutorial on Ada* Exceptions

by

Major Patricia K. Lawlis

lawlis%asu@csnet-relay

Air Force Institute of Technology (AFIT)
and
Arizona State University (ASU)

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Outline

=> Overview

- Naming an exception
- Creating an exception handler
- Raising an exception
- Handling exceptions
- Turning off exception checking
- Tasking exceptions
- More examples

Overview

- What is an exception
- Ada exceptions
- Comparison
  - the American way
  - using exceptions

What Is an Exception

- A run time error
- An unusual or unexpected condition
- A condition requiring special attention
- Other than normal processing

Ada Exceptions

- An exception has a name
  - *may be predefined*
  - may be declared
- The exception is raised
  - may be raised implicitly by run time system
  - may be raised explicitly by raise statement
- The exception is handled
  - exception handler may be placed in any frame
  - exception propagates until handler is found
  - if no handler anywhere, process aborts

The American Way

```
package Stack_Package is

        type Stack_Type is limited private;

        procedure Push (Stack : in out Stack_Type;
                        Element : in Element_Type;
                        Overflow_Flag : out boolean);
        ...

end Stack_Package;


with Text_IO;
with Stack_Package; use Stack_Package;
procedure Flag_Waving is
        ...
        Stack : Stack_Type;
        Element : Element_Type;
        Flag : boolean;
begin
        ...
        Push (Stack, Element, Flag);
        if Flag then
                Text_IO.Put ("Stack overflow");
                ...
        end if;
        ...
end Flag_Waving;
```

Using Exceptions

```
package Stack_Package is

        type Stack_Type is limited private;
        Stack_Overflow,
        Stack_Underflow : exception;

        procedure Push (Stack : in out Stack_Type;
                        Element : in Element_Type);
                    -- may raise Stack_Overflow
        ...
end Stack_Package;


with Text_IO;
with Stack_Package; use Stack_Package;
procedure More_Natural is
        ...
        Stack : Stack_Type;
        Element : Element_Type;
begin
        ...
        Push (Stack, Element);
        ...
exception
        when Stack_Overflow =>
                Text_IO.Put ("Stack overflow");
        ...
end More_Natural;
```

Outline

- Overview

=> **Naming an exception**

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Naming an Exception

- Predefined exceptions
- Declaring exceptions
- I/O exceptions

Predefined Exceptions

- In package STANDARD (also see chap 11 of LRM)

- CONSTRAINT_ERROR

  violation of range, index, or discriminant constraint...

- NUMERIC_ERROR

  execution of a predefined numeric operation cannot deliver a correct result

- PROGRAM_ERROR

  attempt to access a program unit which has not yet been elaborated...

- STORAGE_ERROR

  storage allocation is exceeded...

- TASKING_ERROR

  exception arising during intertask communication

Declaring Exceptions

exception_declaration ::= identifier_list : **exception**;

- Exception may be declared anywhere an object declaration is appropriate

- However, exception is not an object

  - may not be used as subprogram parameter, record or array component

  - has same scope as an object, but its effect may extend beyond its scope

Example:

```
procedure Calculation is

    Singular : exception;
    Overflow, Underflow : exception;

begin
  ...
end Calculation;
```

I/O Exceptions

- Exceptions relating to file processing

- In predefined library unit IO_EXCEPTIONS
  (also see chap 14 of LRM)

- TEXT_IO, DIRECT_IO, and SEQUENTIAL_IO with it

```
package IO_EXCEPTIONS is

        NAME_ERROR     : exception;
        USE_ERROR      : exception;      --attempt to use
                                         --invalid operation
        STATUS_ERROR   : exception;
        MODE_ERROR     : exception;
        DEVICE_ERROR   : exception;
        END_ERROR      : exception;      --attempt to read
                                         --beyond end of file
        DATA_ERROR     : exception;      --attempt to input
                                         --wrong type
        LAYOUT_ERROR   : exception;      --for text processing

end IO_EXCEPTIONS;
```

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Creating an Exception Handler

- Defining an exception handler

- Restrictions

- Handler example

Creating an Exception Handler

- Defining an exception handler
- Restrictions
- Handler example

Defining an Exception Handler

- Exception condition is "caught" and "handled" by an exception handler

- Exception handler may appear at the end of any frame (block, subprogram, package or task body)

```
begin
    ...
exception
    -- exception handler(s)
end;
```

- Form similar to case statement

```
exception_handler ::=
      when exception_choice {| exception_choice} =>
              sequence_of_statements

exception_choice ::= exception_name | others
```

Defining an Exception Handler

- Exception condition is "caught" and "handled" by an exception handler

- Exception handler may appear at the end of any frame (block, subprogram, package or task body)

```
begin
     ...
exception
     -- exception handler(s)
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```

- Form similar to case statement

```
exception_handler ::=
        when exception_choice {| exception_choice} =>
                sequence_of_statements

exception_choice ::= exception_name | others
```

Restrictions

- Exception handlers must be at the end of a frame

- Nothing but exception handlers may lie between **exception** and **end** of frame

- A handler may name any visible exception declared or predefined

- *A handler includes a sequence of statements*

    - response to exception condition

- A handler for **others** may be used

    - must be the last handler in the frame

    - handles all exceptions not listed in previous handlers of the frame (including those not in scope of visibility)

    - can be the only handler in the frame

Handler Example

```
procedure Whatever is

        Problem_Condition : exception;

begin
        ...

exception

        when Problem_Condition =>
                Fix_It;

        when CONSTRAINT_ERROR =>
                Report_It;

        when others =>
                Punt;

end Whatever;
```

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=> **Raising an exception**

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Raising an Exception

- How exceptions are raised
- Effects of raising an exception
- Raising example

How Exceptions are Raised

- Implicitly by run time system

  - predefined exceptions

- Explicitly by **raise** statement

raise_statement ::= **raise** [exception_name];

  - the name of the exception must be visible at the point of the raise statement

  - a raise statement without an exception name is allowed only within an exception handler

Effects of Raising an Exception

- Control transfers to exception handler at end of frame (if one exists)

- Exception is lowered

- Sequence of statements in exception hander is executed

- Control passes to end of frame

- If frame does not contain an appropriate exception handler, the exception is propagated

Raising Example

```
procedure Whatever is

        Problem_Condition  : exception;
        Real_Bad_Condition : exception;

begin
        ...
        if Problem_Arises then
                raise Problem_Condition;
        end if;
        ...
        if Serious_Problem then
                raise Real_Bad_Condition;
        end if;
        ...
exception

        when Problem_Condition =>
                Fix_It;

        when CONSTRAINT_ERROR =>
                Report_It;

        when others =>
                Punt;

end Whatever;
```

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- Overview
- Naming an exception
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- Raising an exception

=> Handling exceptions

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Handling Exceptions

- How exception handling can be useful
- Which exception handler is used
- Sequence of statements in exception handler
- Propagation
- Propagation example

How Exception Handling Can Be Useful

- Normal processing could continue if
  - cause of exception condition can be "repaired"
  - alternative approach can be used
  - operation can be retried
- Degraded processing could be better than termination
  - for example, safety-critical systems
- If termination is necessary, "clean-up" can be done first

Which Exception Handler Is Used

- If exception is raised during normal execution, system looks for an exception handler at the end of the frame in which the exception occurred

- If exception is raised during elaboration of the declarative part of a frame

    - elaboration is abandoned and control goes to the end of the frame with the exception still raised

    - exception part of the frame is not searched for an appropriate handler

    - effectively, the calling unit will be searched for an appropriate handler

    - if elaboration of library unit, program execution is abandoned
        - -- all library units are elaborated with the main program

- If exception is raised in exception handler

    - handler may contain block(s) with handler(s)

    - *if not handled* locally within handler, control goes to end of frame with exception raised

Sequence of Statements in Exception Handler

- Handler completes the execution of the frame
  - handler for a **function** should usually contain a **return** statement
- Statements can be of arbitrary complexity
  - can use most any language construct that makes sense in that context
  - cannot use **goto** statement to transfer into a handler
  - if handler is in a block inside a loop, could use **exit** statement
- Handler at end of package body applies only to package initialization

Propagation

- Occurs if no handler exists in frame where exception is raised

- Also occurs if **raise** statement is used in handler

- Exception is propagated dynamically

  - propagates from subprogram to unit calling it (not necessarily unit containing its declaration)

  - this can result in propagation outside its scope

- Propagation continues until

  - an appropriate handler is found

  - exception propagates to main program (still with no handler) and program execution is abandoned

Propagation Example

```
procedure Do_Nothing is
      -------------
   procedure Has_It is
         Some_Problem : exception;
   begin
         ...
         raise Some_Problem;
         ...
   exception
         when Some_Problem =>
               Clean_Up;
               raise;
   end Has_It;
      -------------
   procedure Calls_It is
   begin
         ...
         Has_It;
         ...
   end Calls_It;
      -------------
begin -- Do_Nothing
      ...
      Calls_It;
      ...
exception
      when others => Fix_Everything;
end Do_Nothing;
```

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=> **Turning off exception checking**

- Tasking exceptions
- More examples

Turning Off Exception Checking

- Overhead vs efficiency
- Pragma SUPPRESS
- Check identifiers

Overhead vs Efficiency

- Exception checking imposes run time overhead

  - interactive applications will never notice
  - real-time applications have legitimate concerns but must not sacrifice system safety

- When efficiency counts

  - first and foremost, make program work
  - be sure possible problems are covered by exception handlers
  - check if efficient enough - stop if it is

  - if not, study execution profile
    - -- eliminate bottlenecks
    - -- improve algorithm
    - -- avoid "cute" tricks

  - check if efficient enough - stop if it is
  - if not, trade-offs may be necessary
  - some exception checks may be expendable since debugging is done

  - however, every suppressed check poses new possibilities for problems
    - -- must re-examine possible problems
    - -- must re-examine exception handlers

  - always keep in mind
    - -- problems <u>will</u> happen
    - -- critical applications must be able to deal with these problems

Moral

Improving the ~~algorithm~~ is far better - and easier in the long run - than suppressing checks

Pragma SUPPRESS

- Only allowed immediately within a declarative part or immediately within a package specification

pragma SUPPRESS (identifier [,[ON =>] name]);

  - identifier is that of the check to be omitted (next slide lists identifiers)
  - name is that of an object, type, or unit for which the check is to be suppressed
    - -- if no name is given, it applies to the remaining declarative region

- An implementation is free to ignore the suppress directive for any check which may be impossible or too costly to suppress

Example:

pragma SUPPRESS (INDEX_CHECK, ON => Index);

Check Identifiers

- These identifiers are explained in more detail in chap 11 of the LRM

- Check identifiers for suppression of CONSTRAINT_ERROR checks

  ACCESS_CHECK
  DISCRIMINANT_CHECK
  INDEX_CHECK
  LENGTH_CHECK
  RANGE_CHECK

- Check identifiers for suppression of NUMERIC_ERROR checks

  DIVISION_CHECK
  OVERFLOW_CHECK

- Check identifier for suppression of PROGRAM_ERROR checks

  ELABORATION_CHECK

- Check identifier for suppression of STORAGE_ERROR check

  STORAGE_CHECK

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=> **Tasking exceptions**

- More examples

Tasking Exceptions

- Exception handling is trickier for tasks
- Exceptions during task rendezvous
- Tasking example

Exception Handling Is Trickier for Tasks

- Rules are not really different, just more involved
  - local exceptions handled the same within frames

If exception is raised

- during elaboration of task declarations
  - the exception TASKING_ERROR will be raised at the point of task activation
  - the task will be marked completed
- during execution of task body (and not resolved there)
  - task is completed
  - exception is not propagated
- during task rendezvous
  - this is the really tricky part

Exceptions During Task ~~Rendezvous~~

- If the **called** task terminates abnormally

  exception TASKING_ERROR is raised in **calling** task at the point of the entry call

- If the **calling** task terminates abnormally

  no exception propagates to the **called** task

- If an exception is raised in **called** task within an **accept** (and not handled there locally)

  the same exception is raised in the **calling** task at the point of the entry call
  (even if exception is later handled outside of the accept in the called task)

- If an entry call is made for entry of a task that becomes completed before accepting the entry

  exception TASKING_ERROR is raised in **calling** task at the point of the entry call

Tasking Example

```
procedure  Critical_Code  is

        Failure : exception;
        -------------
        task  Monitor  is
                entry Do_Something;
        end Monitor;
        task  body  Monitor  is
        ...
        begin
                accept  Do_Something  do
                        ...
                        raise  Failure;
                        ...
                end  Do_Something;
                ...
        exception   -- exception handled here
                when Failure =>
                        Termination_Message;
        end Monitor;
        -------------
begin  -- Critical_Code
        ...
        Monitor.Do_Something;
        ...
exception   -- same exception will be handled here
        when Failure =>
                Critical_Problem_Message;

end   Critical_Code;
```

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=> **More examples**

More Examples

- Interactive data input
- Propagating exception out of scope and back in
- Keeping a task alive

Interactive Data Input

```
with Text_io; use Text_io;
procedure Get_Input (Number : out integer) is

    type Input_Type is integer range  0..100;
    package Int_io is new Integer_io (Input_Type);
    In_Number : Input_Type;

begin  -- Get_Input

    loop            -- to try again after incorrect input

        begin  -- inner block to hold exception handler

            put ("Enter a number 0 to 100");
            Int_io.get (In_Number);
            Number := In_Number;
            exit;  -- to exit loop after correct input

        exception
            when DATA_ERROR | CONSTRAINT_ERROR =>
                put ("Try again, fat fingers!");
                Skip_Line;    -- must clear buffer

        end; -- inner block

    end  loop;

end  Get_Input;
```

Propagating Exception Out of Scope and Back In

```
declare
    package Container is
        procedure Has_Handler;
        procedure Raises_Exception;
    end Container;
     ----------
    procedure Not_in_Package is
    begin
        Container.Raises_Exception;
    exception
        when others => raise;
    end  Not_in_Package;
     ----------
    package body Container is
        Crazy : exception;
        procedure Has_Handler is
        begin
            Not_in_Package;
        exception
            when Crazy => Tell_Everyone;
        end Has_Handler;
        procedure Raises_Exception is
        begin
            raise Crazy;
        end Raises_Exception;
    end Container;
begin
    Container.Has_Handler;
end;
```

Keeping a Task Alive

```
task Monitor is
      entry Do_Something;
end Monitor;

task body Monitor is
begin
      loop       -- for never-ending repetition
            ...
            select
                  accept Do_Something do

                        begin  -- block for exception handler
                              ...
                              raise Failure;
                              ...
                        exception
                              when Failure => Recover;
                        end;  -- block

                  end Do_Something;  -- exception must be
                                     -- lowered before exiting
                  ...
            end select;
            ...
      end  loop;

exception
      when others =>
            Termination_Message;
end Monitor;
```

SUMMARY

- know the topic well
- use good visual aids
- make organization obvious
- don't leave this as an isolated topic
  continue to use exceptions forever after

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